STATUS OF *SCHOENOPLECTUS HALLII* (HALL'S BULRUSH) (CYPERACEAE) IN THE UNITED STATES

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ABSTRACT

New information is provided on the distribution, ecology and life history, threats, research needs and conservation status for Hall's bulrush (*Schoenoplectus hallii*). Additional information is presented on taxonomy, the status of Hall's bulrush in each state where it has been recorded, management recommendations, and the adequacy of any regulatory mechanisms in place to protect or manage the species' habitat. A history is provided for previous evaluations of Hall's bulrush by the U.S. Fish and Wildlife Service, and the species' potential as a candidate for official listing under the Endangered Species Act of 1973.

RESUMEN

Se aporta nueva información sobre la distribución, ecología y historia vital, amenazas, necesidades de investigación y estado de conservación de la espadaña (*Schoenoplectus hallii*). Se presenta información adicional sobre su taxonomía, el estatus de la espadaña en todos los estados donde se ha citado, recomendaciones sobre su manejo, y lo apropiado de cualquier mecanismo de regulación para proteger o manejar el hábitat de la especie. Se aporta una historia de las evaluaciones previas de la espadaña por el U.S. Fish and Wildlife Service, y el potencial de la especies como candidata para estar colocada en la lista oficial de la Ley de Especies Amenazadas de 1973.

INTRODUCTION

McKenzie (1998) provided an initial range-wide conservation status assessment of Hall's bulrush (*Schoenoplectus hallii*) (A. Gray) S.G. Smith, which included information on distribution, ecology and life history, threats, research needs, and conservation status. Beatty et al. (2004) included a summary of some new information on *S. hallii* in a conservation assessment for the species in Region 2 of the U.S. Forest Service (USFS), but the main focus of their report was Kansas and Nebraska. Since McKenzie's (1998) analysis, new information on the species' distribution, germination requirements, and threats to its continued existence has been reported. The purpose of this paper is to summarize information received from published and unpublished reports that have been completed since the 1998 assessment (McKenzie 1998). Due to the potential confusion of *S. hallii* with the closely related *S. erectus* (Poir.) Palla ex J. Raynal and *S. saximontanus* (Fernald) J. Raynal, reports of *S. hallii* throughout the United States were re-evaluated by Ernie Schuyler of the Philadelphia Academy of Natural Sciences or S.G. Smith (Schuyler 1969; S.G. Smith, pers. comm.).

Taxonomy

Taxonomic nomenclature for plants used in this report follows Yatskievych (1999) or Yatskievych & Turner (1990) except for *Lesquerella fendleri* which follows Great Plains Flora Association (1986), *S. erectus* which follows Smith (2002b), *Nymphoides peltata* which follows Gleason and Cronquist (1991), and *Clarkia springvillensis, Lolium multiflorum,* and *Gilia achilleifolia* which follow Hickman (1993).

Schoenoplectus hallii belongs to *Schoenoplectus* section *Supini* (Cherm.) J. Raynal, in the Cyperaceae. Until recently the genus *Schoenoplectus* (Rchb.) Palla was generally included in the genus *Scirpus* L. sensu lato (e.g., Gleason & Cronquist 1991; Tucker 1987; Schuyler 1969). *Schoenoplectus* sect. *Supini* has been confused with *S.* sect. *Actaeogeton*, but it can be distinguished from that group by the frequent occurrence

of amphicarpy (the production of solitary pistillate flowers enclosed in sheaths of basal leaves in addition to bisexual flowers in spikelets at the culm tips), which occurs in all North American species in the section, the lack of perianth (except rarely in basal flowers), and, in North American species, the presence of a cauline leaf (Smith 2002b; Smith & Hayasaka 2001, 2002). Recent investigations have led to division of *Scirpus* sensu lato into various segregate genera (e.g., Wilson 1981; Weber & Wittmann 1992; Strong 1994; Smith 1995, 2002b; Smith & Yatskievych 1996; Yatskievych 1999; Smith 2002b; Flora of North America Editorial Committee 2002). *Schoenoplectus hallii* is currently recognized by most taxonomists as the correct name for the species (Smith 1995). Raynal (1976) placed *Schoenoplectus hallii* in synonymy with *S. erectus*, but Smith (1995) provided convincing evidence why Raynal's treatment was invalid. Today most taxonomists agree that *S. hallii* is a valid, distinct species.

Schoenoplectus hallii is most similar to *S. erectus*, which is known from FL, GA, SC, TX, Mexico, South America, Asia, Africa and Australia, and *S. saximontanus*, which is known from British Columbia, CA, CO, KS, MO, NE, OH, OK, SD, TX, UT, and Mexico (Smith 2002b).

Description

A small to medium-sized, tufted annual, with short rhizomes hidden among the aerial stem bases; culms 4–45 cm long, to 1 mm wide, stiff to flaccid, cylindric, leaves 3–4 basal and one cauline, blades 1–2, 0.1–20 cm long, to 1 mm wide; lowest involucral bract sometimes resembling a continuation of the culm, 3–15 cm long, about one-half as long as the culm; inflorescence consisting of 1–7 sessile spikelets in a head-like cluster, or rarely with 1 or 2 short branches; spikelets ovoid to lanceoloid, 5–20 mm long, 2.0–3.5 mm wide; spikelet scales 2.5 to ca. 4.0 mm long, tan or pale orange-brown to straw-colored as they age, ovate, midrib region often green, midrib projecting as a short cusp (mucro) past the body of the scale; solitary pistillate flowers sometimes present at the base of the culm, enclosed by an encircling leaf sheath (most frequent late in the flowering season); perianth bristles absent; stigmas 2 or 3 in basal flowers; achenes ovoid to obovoid or nearly circular, base abruptly contracted to a short neck, apex with an abrupt beak 0.1 mm long; concave (rarely nearly flat) on one side and convex on the other, transversely rugose (corrugated) with about 15–18 conspicuous cross-wrinkles on each side, 1.3–2.0 mm long, brown when young, dark brown to black at maturity; basal achenes significantly larger (Smith et al. 2006), unequally 3-angled; $2n = 22$.

Schoenoplectus hallii is very similar to the other two species of *Schoenoplectus* sect. *Supini* that occur in North America: *S. erectus* and *S. saximontanus* (Smith 2002b). In contrast to the achenes of *S. hallii* as described above, the achenes of *S. erectus* are strongly convex on one side and slightly convex on the other side and have 10–15 ridges on the most convex side. Both *S. hallii* and *S. erectus* can be distinguished from *S. saximontanus* by their two-branched styles (three-branched in *S. saximontanus*) and by their two-sided achenes (3-sided in *S. saximontanus*). *Schoenoplectus erectus* differs from *S. hallii* and *S. saximontanus* in the color of its spikelet scales, which are bright orange on their bases and toward their tips.

Some specimens from a mixed population of *S. hallii* and *S. saximontanus* in Oklahoma have a high percentage of aborted achenes or achenes that are morphologically intermediate between the two species and may be hybrids (Magrath 2002; Smith et al. 2004). Some specimens from southwestern Georgia may be *S. erectus* × *S. hallii* hybrids (Smith 2002b).

Reported range

There is controversy in the literature concerning the historical range (pre-1981) of *S. hallii*. Previous reports from Alabama (U.S. Fish & Wildlife Service 1993), Colorado (Harrington 1954; Small 1972; U.S. Fish & Wildlife Service 1993), Florida (Beetle 1947; Koyama 1962; Radford et al. 1964; Mohlenbrock 1976; Great Plains Flora Association 1986; Robertson et al. 1994), South Carolina (Radford et al. 1964; U.S. Fish & Wildlife Service 1993), South Dakota (Great Plains Flora Association 1977), and Texas (Correll & Johnston 1970; Small 1972; Mohlenbrock 1976; Great Plains Flora Association 1986; U.S. Fish & Wildlife Service 1993; Beatty et al. 2004; O'Kennon & McLemore 2004) are either based on misdeterminations of *S. saximontanus* along the western edge of the species range, or misidentifications of *S. erectus* from the southern United States (Rolfsmeier 1995; McKenzie 1998; Smith 2002b). Further, many county records from states

where *S. hallii* has been documented, as reported by the Great Plains Flora Association (1977), were based on misdeterminations of *S. saximontanus* (Rolfsmeier 1995; McKenzie 1998; Smith 2002b). A report for Oregon (Koyama 1962) was due to the misreading of the label on a specimen from near the village of Oregon, Dane County, WI. A record for Decatur County, GA, based on a voucher specimen at the State of Georgia Herbarium (T. Patrick, Georgia DNR, pers. comm.), had been previously re-determined by Schuyler (1969) to be *S. erismanae* [= *S. erectus* (Schyuler, Philadelphia Academy of Natural Sciences, pers. comm.)], and four collections from Baker and Decatur counties, GA and originally identified as *S. hallii* were redetermined by S.G. Smith to be *S. erectus* (S.G. Smith, pers. comm.).

Based on verification of specimens by Schuyler or S.G. Smith, the documented pre-1981 range for *S. hallii* is GA, IL, IA, KS, MA, MI, MO, NE, and WI (Table 1) (McKenzie 1998; Smith 2002b; Beatty et al. 2004). *Schoenoplectus hallii* has been extirpated from Massachusetts where it was last collected in 1908, and the lack of documentation since 1946 suggests that the species may have been extirpated from Georgia (McKenzie 1998; O'Kennon & McLemore 2004; NatureServe 2006). Schuyler or S.G. Smith has confirmed the identification of specimens of *S. hallii* collected from 10 states within the last 25 years (Table 1) (Smith 2002b; O'Kennon & McLemore 2004). Texas has recently been included in the range of *S. hallii* based on the discovery of the species in the state in 2003 (O'Kennon & McLemore 2004).

Apparent changes in distribution and status of *S. hallii* in the United States

For the following reasons, it is extremely difficult to assess any apparent changes in the distribution and status of *S. hallii*: 1) population numbers of this species vary widely from year to year depending on the availability of suitable wetland habitat, 2) populations may fail to emerge at some sites for many years, but re-emerge when conditions are favorable for germination, and 3) the species is frequently confused with *S. saximontanus* and *S. erectus*.

Due to the persistence of the achenes in the seed bank, the Nature Conservancy considers any site where *S. hallii* has been recorded within the last 25 years to be extant (Ostlie 1990; Ostlie & Gottlieb 1992). To determine if there has been any apparent change in the distribution and status of this species, we followed the Nature Conservancy's criterion and first analyzed all documented county and single locality records of *S. hallii* older than 25 years (Table 1, Table 2; Fig. 1). We compared that information with documented records of the species within the last 25 years (Table 1, Table 3; Fig. 2) and within the last five years (Table 1, Table 4; Fig. 3). We found that determining the exact number of records was problematic due to: 1) the frequent misidentification of specimens, 2) the lack of specific locality data given for some collections, 3) over-counting of populations that resulted when sites that were within 1 km of one another were recorded as separate sites, and 4) the failure to monitor some known sites, especially during years when drought conditions persist or when there was a lack of flooded conditions needed for germination and growth. Despite these limitations, we obtained sufficient information for comparing records within the last five and 25 years and what was known and confirmed historically.

Prior to 1981, *S. hallii* was documented at approximately 30 sites distributed across 15 counties in nine states (Table 1, Table 2). Within the last 25 years, *S. hallii* has been confirmed from approximately 84 sites scattered across 26 counties in 10 states (Table 1, Table 2). The increased number of sites documented between 1981 and 2006 largely reflects recent surveys that were conducted in IL, MO, NE and OK during years when conditions were optimal for the species (Table 1, Table 2). Over 79% of records confirmed within the last 25 years have been from IL, MO, and NE (Table 1). Within the last five years, *S. hallii* has been collected at 25 sites from 11 counties in only six states: eight sites in Missouri, six sites in Nebraska, but only one site each in IL, IN, KY, MI, OK, and TX, and none in GA, IA, KS, or MA (Table 1, Table 4). The paucity of records within the last five years may be due to drought conditions that reduced available habitat or reflect a failure to monitor sites. In Wisconsin, abnormally high rainfall flooded the only known site and prevented a survey in 2006 (S.G. Smith pers.comm.). Despite the fewer documented sites within the last five years, new populations have been recently confirmed for Indiana (M. Homoya, braska (Steinauer 2001a,b), Oklahoma (Magrath 2002; Smith 2002b) and Texas (O'Kennon &

Table 1. Approximate number of sites where *Schoenoplectus hallii* was documented historically (i.e., prior to 1981), or where the species has been confirmed within the last 25 years, and within the last 5 years.

State	Number of sites		
	Historical	Last 25 years	Last 5 years
GA	1	0	0
IA	1	0	0
IN	0	6	3
IL	~13	~29	1
KS	7	3	0
KY	0	1	1
MA	2	0	0
MI	1	5	1
MO	2	10	10
NE	2	27	6
OK	0	1*	1*
TX	0	1	1
WI	1	1	1
Total	~30	84	25

*Includes 14 ponds

Table 2. Counties with historical records of *Schoenoplectus hallii* prior to 1981.

State	County
GA	Dougherty
IL	Cass, Mason, Menard
IA	Muscatine
KS	Harvey, Reno
MA	Essex, Middlesex
MI	Muskegon
MO	Howell, St. Louis
NE	Holt, Rock
WI	Dane

Table 3. Counties where *Schoenoplectus hallii* has been documented within the last 25 years.

State	County
IL	Alexander, Cass, Kankakee, Mason, Morgan
IN	Daviess, Lake, Porter
KS	Harper, Reno
KY	Christian
MI	Allegan, Muskegon
MO	Howell, Scott
NE	Brown, Garfield, Holt, Loup, Rock, Wheeler
OK	Atoka, Comanche, Johnston
TX	Wise
WI	Dane

Table 4. Counties with documented records of *Schoenoplectus hallii* within the past five years.

State	County
IL	Mason
IN	Daviess, Lake
MO	Howell, Scott
NE	Brown, Holt, Rock, Wheeler
OK	Comanche
TX	Wise

Indiana DNR, pers. comm.), Ne McLemore 2004). It is likely that *S. hallii* has been extirpated from Massachusetts and possibly Georgia (McKenzie 1998; Smith 2002b; O'Kennon & McLemore 2004; NatureServe 2006).

Documented records of *S. hallii* suggest that it has always been a rare species in most states as reported by Schuyler (1969; pers. comm.) and S.G. Smith (pers. comm.). While this still may be the case, the lack

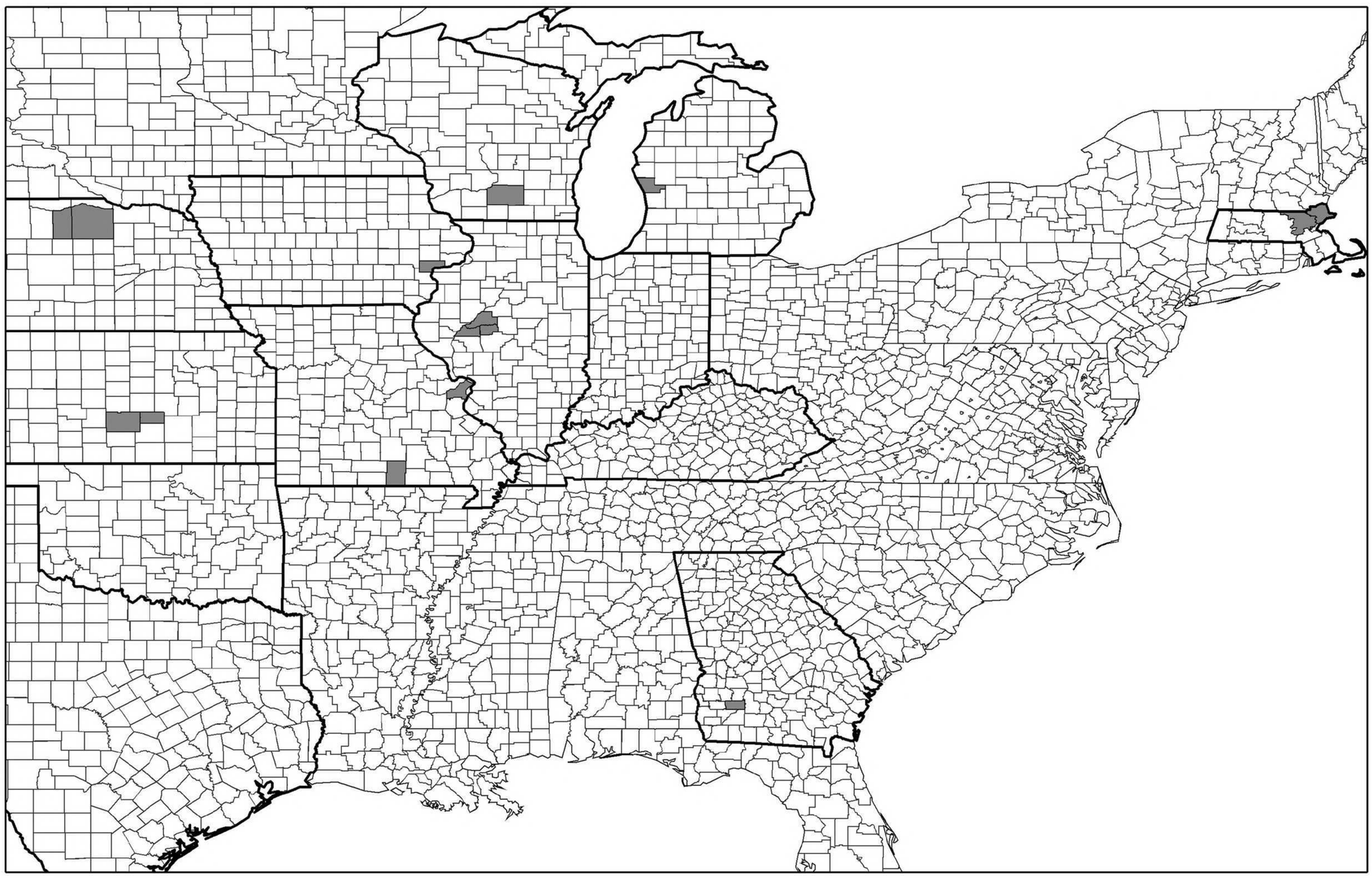

Fig. 1. Documented, historical county records of *Schoenoplectus hallii* in the United States prior to 1981.

of extensive surveys for the species in states where there is abundant available habitat, and during years when habitat conditions are suitable, prevents an accurate picture of the distribution of *S. hallii* in North America.

Habitat and Life History/ Ecology

Schoenoplectus hallii is an obligate wetland species (Reed 1988; Swink & Wilhelm 1994; McClain et al. 1997; McKenzie 1998; Penskar & Higman 2003; Beatty et al. 2004). Reported habitats are often characterized by fluctuating water levels (Ostlie 1990; Ostlie & Gottlieb 1992; McKenzie 1998; Beatty et al. 2004; O'Kennon & McLemore 2004). *Schoenoplectus hallii* has been described as a "specialized, primary successional plant with a narrow niche" (G. Yatskievych, MOBOT, pers. comm.) that colonizes "sandy pioneer habitat" (Schuyler 1969), and it is usually found on bare soil where fluctuating water levels may prevent the establishment of competing perennials (Schuyler 1969). It has been reported from the edges of ephemeral pools, sinkhole and sand ponds (Schuyler 1969; Robertson et al. 1994; McClain et al. 1997; McKenzie 1998; Smith 2002b; Beatty et al. 2004), sandy clay ponds (O'Kennon & McClemore 2004) and sand prairies (Schuyler 1969; McKenzie1998), sand pits (Bowles et al. 1990), ditches (Steinauer 2001a; Smith 2002b), wet places in cultivated fields (Smith 2002b), "silty, muddy flats" (Chester 1988), and "cattle trails that lead through shallow-water wetlands and other depressions" (Beatty et al. 2004). Occasionally, the species can be found in rocky or cobble habitat. Rocks are along the edges of the sinkhole pond habitat in Missouri (Schuyler 1969; McKenzie 1998) and the species was associated with "many cobbles" at the recent rediscovery site in Wisconsin (S.G. Smith, pers. obs.).

During years when spring rainfall or high river levels create suitable wetland habitat, *S. hallii* can often

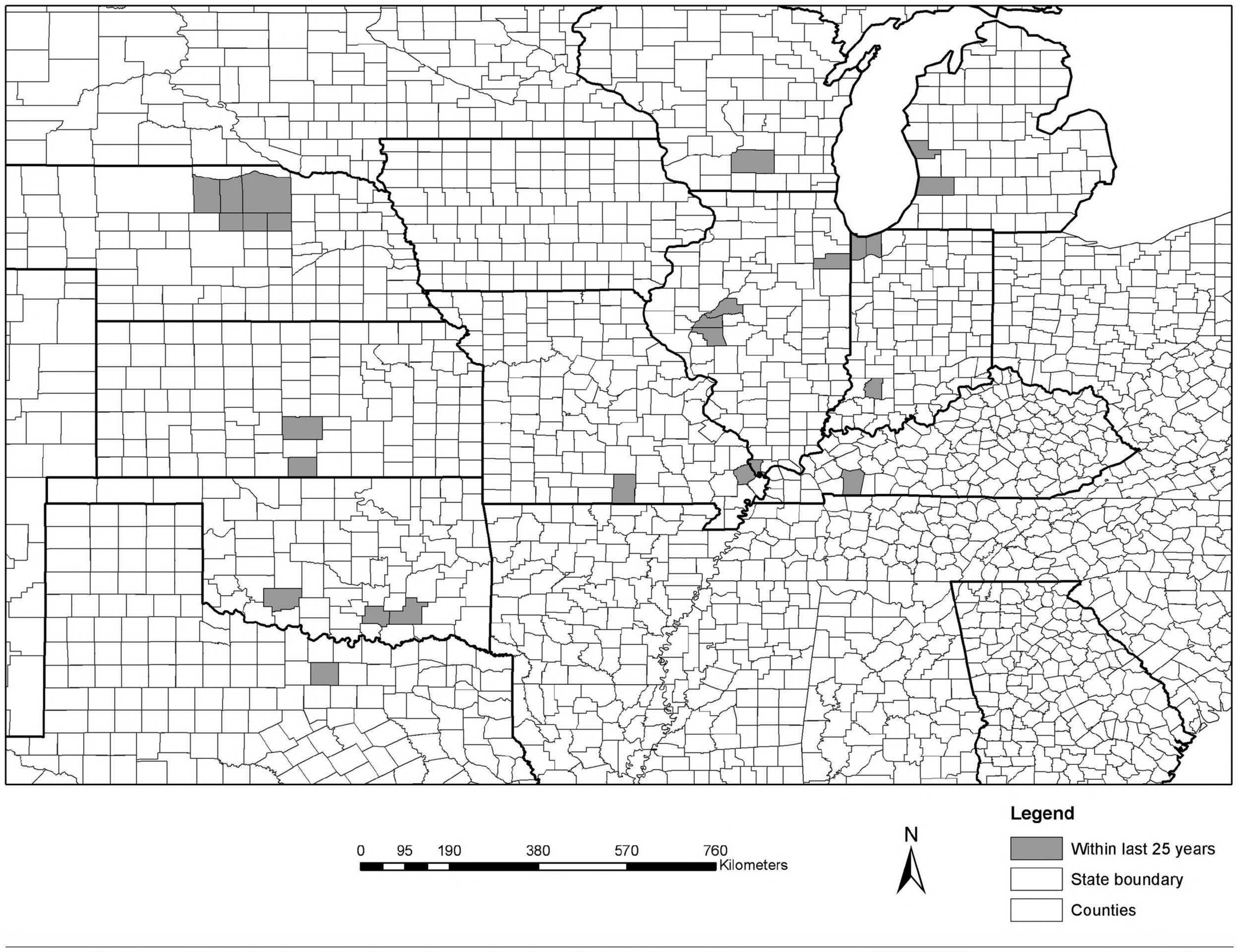

Fig. 2. Documented, county records of *Schoenoplectus hallii* in the United States within the last 25 years.

be found in abundance in the low depressions of cultivated fields in IL, KY, and MO (Chester 1988; Robertson et al. 1994; McClain et al. 1997; Missouri Natural Heritage Program 2006a). In drier years, these areas lack wetland habitat and are cultivated for crops (Chester 1988; Robertson et al. 1994; McClain et al. 1997). Although the species is usually associated with sandy soil, it can be found on exposed mud with a high silt content (Chester 1988). At one site in southern Missouri, Smith (2001) determined that *S. hallii* does not survive below 14% soil moisture and inhabits soils with a range of organic matter from 0.3–2.6%.

Schoenoplectus hallii germinates sporadically from year to year depending on the availability of wet, exposed habitat (Schuyler 1969; Penskar & Higmann 2003; Robertson et al. 1994). In some areas, the species can disappear for long periods only to reappear when conditions are favorable for germination and growth (Robertson et al. 1994; Chester 1988; McKenzie 1998; McClain et al. 1997; Penskar & Higman 2003). In Illinois, populations can vary from hundreds of thousands of plants covering extensive areas in one year to being entirely absent in other years (Robertson et al. 1994; McClain et al. 1997; McKenzie 1998; Beatty et al. 2004).

The exact mechanisms necessary to initiate seed germination and development of mature plants are only beginning to be understood. Smith (2001, 2002a, 2003) and Baskin et al. (2003) concluded that the species requires a combination of flooding, ethylene and light for germination, and that dormancy, which occurs in mature seeds, is more readily broken if flooded conditions occur in late spring and summer rather than late winter or early spring. Smith & Houpis (2004) investigated gas exchange in response to vapor pressure deficit in *S. hallii* and determined that the stomates of the species do not close in response

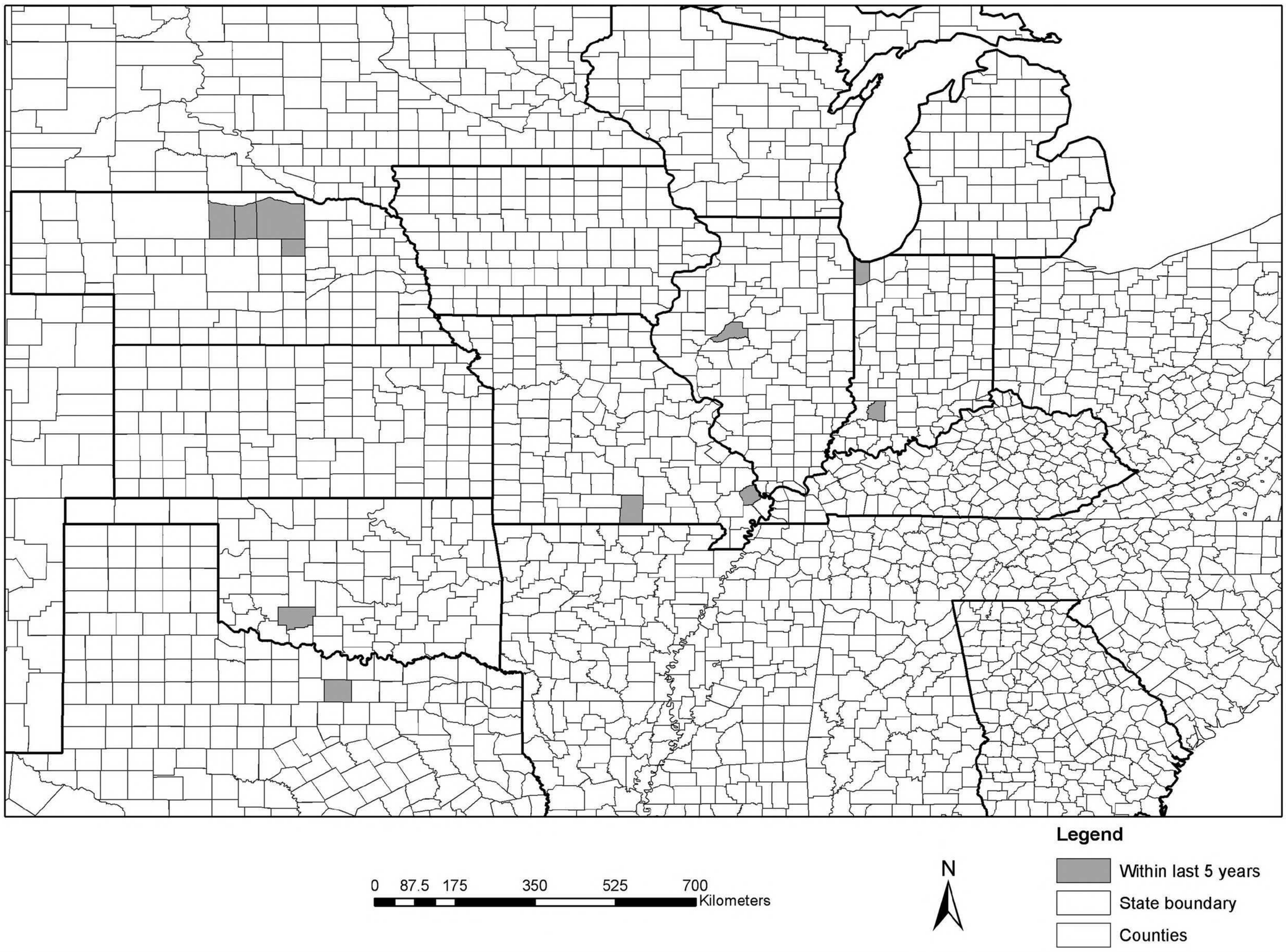

Fig. 3. Documented, county records of *Schoenoplectus hallii* in the United States within the last 5 years.

to increasing drought. This condition imposes a constraint on the species, requiring that it take advantage of optimal transient conditions to complete its lifecycle before conditions become unsuitable.

Studies by Smith (2001, 2002a, 2003) and Penskar & Higman (2003) have determined *S. hallii* can produce a seed bank containing thousands of achenes. These achenes apparently remain dormant for decades until conditions are optimal for germination and growth (Robertson et al.1994; McClain et al. 1997; McKenzie 1998; Beatty et al. 2004; NatureServe 2006). This is a strategy noted for other species of sedges (Baskin et al. 2000) and plants associated with desert environments (Venable & Lawlor 1980).

The biological and ecological significance of amphicarpy in *S. hallii* and other members of *Schoenoplectus* Section *Supini* have received little attention in the literature. Browning (1992) suggested that amphicarpy in the genus *Schoenoplectus* was environmentally induced due to a decrease in water levels. Others have postulated that amphicarpy has evolved to protect fruits from herbivory or changes in microclimate (Bruhl 1994; Magrath 2002).

The dispersal mechanism for the transport of achenes of *S. hallii* is not known, but some have suggested that the species is spread by migratory waterfowl (McClain et al. 1997; Beatty et al. 2004) that have been found to transport the seeds of other plant species long distances (deVlaming & Proctor 1968; Dunn and Knauer 1975; Powers et al. 1978; Kantud 1996). Magrath (2002) postulated that large herbivores such as cattle and bison were the likely dispersal agents for achenes of *S. hallii* on the Wichita Mountains Wildlife Refuge in Oklahoma, and Mike Homoya of the Indiana DNR hypothesized that the discovery of *S. deltarum* (Schuyler) Soják in Indiana was due to migrating waterfowl.

Associated Species

Schoenoplectus hallii is usually associated with other wetland-adapted plants. Although associates have not been provided for many sites, detailed data collected at others (e.g., Voss 1967; Robertson et al. 1994; Swink & Wilhelm 1994; McClain et al. 1997; Steinauer 2001a; Penskar & Higman 2003; O'Kennon & McLemore 2004) reveal the following commonality of wetland-adapted taxa: *Agrostis* spp., *Alisma* spp., *Ammania* spp., *Bacopa* spp., *Cyperus* spp., *Echinochloa* spp., *Eleocharis* spp., *Fimbristylis autumnalis* (L.) Roemer & Schultes, *Heterantha* spp., *Hypericum* spp., *Isoetes* spp., *Juncus* spp., *Leersia* spp., *Lindernia* spp., *Lipocarpha micrantha* (M.Vahl) G. Tucker, *Ludwigia* spp., *Lycopus* spp., *Polygonum* spp., *Rhexia* spp., *Rhynchospora* spp., *Rorippa* spp., *Rotala ramosior* (L.) Koehne, *Sagittaria* spp., *Schoenoplectus* spp., *Scirpus* spp., *Typha* spp., and *Xyris* spp. *Echinodorus tenellus* (Mart.) Buchenau var. *parvulus* (Engelm.) Fassett, a species for which the U.S. Fish & Wildlife Service (USFWS) has concern and which is listed as endangered in most mid-western states, has been recorded at *S. hallii* sites in GA, KY, MI, and at five sites in Missouri (Voss 1967; Chester 1988; Robertson et al. 1994; McKenzie 1998; Penskar & Higman 2003; Missouri Natural Heritage Program 2006a).

State Accounts

Alabama.—Previous reports of *S. hallii* in Alabama are referable to *S. erectus* (S.G. Smith, pers. comm.) and recent searches for the species have failed to document its occurrence in the state (A. Schotz, Alabama Heritage Program, pers. comm.).

Colorado.—Previously published accounts of *S. hallii*'s occurrence in the state (Harrington 1954; Small 1972; U.S. Fish & Wildlife Service 1993) are based on misdeterminations of *S. saximontanus* (Schuyler, pers. comm.; Smith 2002b).

Florida.—There are no documented records of this species in Florida and investigations by Smith (2002b) have determined that previous records of *S. hallii* from Florida are referable to *S. erectus*.

Georgia.—*Schoenoplectus hallii* has been documented solely from Dougherty County (Schuyler 1969; S.G. Smith, pers. comm.), and the species has not been collected in the state since 1966 (Patrick, pers. comm.). Previous reports from Decatur and Baker counties have proven to be *S. erectus* (Schuyler 1969). A specimen taken in Decatur County by Thorne [collection number 6553 and identified as *S. hallii*, has not been located (Patrick, pers. comm.)] nor examined by S.G. Smith (pers. comm.). Given that the specimen was collected close to a site (and apparently in the same year) where Thorne collected (collection number 6536), a specimen of *S. erectus* that was misidentified as *S. hallii* (S.G. Smith, pers. comm.), it is likely that the material is also *S. erectus*. Without knowing the correct identification of Thorne's collection number 6553 and with no recent surveys being conducted for *S. hallii*, the exact status of the species in this state is unclear (McKenzie 1998; O'Kennon & McLemore 2004).

Illinois.—The type specimens for *Schoenoplectus hallii* were taken in Illinois (Gray 1863; Winterringer 1959; Schuyler 1969; Mohlenbrock 1976), and more records of the species have been documented here than in any other state. It was historically recorded from Cass (Winterringer 1959; Schuyler 1969; Mohlenbrock & Ladd 1978), Mason (Winterringer 1959; Schuyler 1969; Mohlenbrock 1976; Mohlenbrock & Ladd 1978), and Menard (Winterringer 1959; Mohlenbrock 1976; Mohlenbrock & Ladd 1978) counties (Table 2). The species was discovered in Alexander County in 1993 (T. Kleninger, Illinois Natural Heritage Database, pers. comm.), and it was documented at 27 sites in Cass, Kankakee, Mason and Morgan counties following surveys in 1993 (Robertson et al.1994). Approximately 29 sites have been documented in the state within the last 25 years (Kleninger, pers. comm.) (Table 1). Populations ranged in size from "one plant to thousands of plants forming nearly pure stands and covering several acres" (Robertson et al. 1994). In 1995, when habitat was optimal for the species, some populations covered several acres and included hundreds of thousands of plants that were observed in flooded agricultural fields that were too wet for farm equipment (McClain et al. 1997; McKenzie 1998). Searches for *S. hallii* in Illinois in 1996 at the same sites yielded only one plant and none in 1997 (B. McClain, Illinois DOC, pers. comm.). It has apparently been observed at only one site in Mason County within the last five years (Bill McClain, pers. comm. 2006).

Indiana.—*Schoenoplectus hallii* was first discovered in Porter County in 1981 by Dritz et al. (Bowles et al.

1990; Swink & Wilhelm 1994). It was later discovered at one site in Lake County and at two additional sites in Porter County (Swink & Wilhelm 1994; Homoya, pers. comm.; R. Hellmich, Indiana DNR, pers. comm.). A sixth population was found in Daviess County in 2002 (Hellmich, pers. comm.). Population estimates at these sites range from "a few plants" to "10,000+" plants at the new site in Daviess County (Homoya, pers. comm.; Hellmich, pers. comm.). In 2006, the species was observed at the Daviess County site on 14 June, which is the earliest date recorded for this species in the Midwest. Because there are no active searches for *S. hallii*, it is not known if the species is more widely distributed in Indiana.

Iowa.—Iowa was mistakenly omitted from the range map for *S. hallii* in Smith (2002b). An 1890 record for Muscatine County (Davidson 1959; Guldner 1960; Roosa et al. 1989) was recently confirmed (S.G. Smith, pers. comm.). A very immature but identifiable Reppert s.n. collection taken from Muscatine County in 1890 was discovered and examined by S.G. Smith in 1997 at the Putnam Museum of History and Natural Science in Davenport, Iowa (S.G. Smith, pers. comm.). The specimen that is the basis for a 1960 report from Louisa County (Roosa et al. 1989), however, has not been located nor verified (S.G. Smith, pers. comm.; John Pearson Iowa DNR, pers. comm.). Although Roosa et al. (1989), Robertson et al. (1994), McKenzie (1998), and Beatty et al. (2004) reported that *S. hallii* was probably extirpated from the state, it is listed as a species of "Special Concern" (Iowa Department of Natural Resources 2007) and Pearson believes that there is still sand prairie habitat in Muscatine and Louisa counties that should be searched (pers. comm.).

Kansas.—Historically, *S. hallii* was reported from five counties (Great Plains Flora Association 1977); but it has only been documented from three counties based on correctly-identified voucher specimens: Harper, Harvey and Reno (R. McGregor, C. Freeman and C. Morse, University of Kansas, pers. comm.; S.G. Smith, pers. comm.). Population estimates range from "a few plants" to "abundant" (McGregor and Freeman, pers. comm.). The species has not been observed in the state since 1997 despite intensive surveys of sand prairie communities by several investigators (Freeman, pers. comm.).

Kentucky.—*Schoenoplectus hallii* was first discovered in Kentucky by Chester in 1983 in Christian County (Chester 1988). Since its original discovery, Chester has annually monitored the population at the only known site in the state, where the numbers of plants have been estimated in the thousands (Chester, Austin Peay State Univ., pers. comm.).

Massachusetts.—The occurrence of *S. hallii* in Massachusetts is based solely on historical collections made in Middlesex and Essex counties. The species was recorded from along the shoreline of Winter Pond in Middlesex County between 1876 (Schuyler 1969) and 1931 (Ostlie 1990). A second, undated specimen taken from Essex County by Horner at S. Georgetown and reported by Sorrie (1987) and Ostlie (1990) is housed at the New England Botanical Club herbarium and has been confirmed by Schuyler (pers. comm.). Sorrie (1987) reported that *S. hallii* has been extirpated from Massachusetts and stated that recent efforts to find suitable habitat for the species had failed. Consequently, the species is believed to have been extirpated in the state (McKenzie 1998; Smith 2002b).

Michigan.—First recorded at Carr Lake in Muskegon County in 1900 (Voss 1967), *S. hallii* has since been documented at four additional sites: two in Muskegon County and two in Allegan County (Brodowicz 1990; Penskar, Michigan Natural Features Inventory, pers. comm.; Penskar & Higman 2003). The species was last collected in Muskegon County in 1988 and in Allegan County in 2002 (Penskar, pers. comm.). In favorable years, *S. hallii* can be abundant at Michigan sites. Brodowicz (1990) estimated "hundreds of plants" at a Muskegon County site he visited in 1988 and Penskar (pers. comm.) reported that numbers at Michigan sites range from a few stems to tens of thousands of plants. Several years of intensive searching by experts have failed to yield any additional populations, but Penskar & Higman (2003) reported that suitable habitat exists that has not yet been surveyed. The failure to observe the species in Michigan since 2002 may be due to the drought that persists at some localities in the Midwest (Penskar & Higman 2003).

Missouri.—Historically, *S. hallii* was known from Howell and St. Louis counties (Steyermark 1963). The inscription "hills west of St. Louis" on a collection by Englemann in 1845 (five specimens in different herbaria), which was cited in the original description, provides documented evidence of the species' oc-

currence in St. Louis County (Yatskievych, pers. comm.). There are currently 10 extant sites in the state: three are located along the edges of sinkhole ponds in Howell County and seven are along the edges of sand depressions, swales, or ponds in Scott County (Missouri Natural Heritage Program 2006a). Population size fluctuates widely from year to year at most of the extant sites. As few as four plants have been documented at one of the sinkhole pond sites (T. Smith, Missouri DOC, pers. comm.), but hundreds of thousands of plants were estimated in 1998 and 2002 at sites in Scott County during years when conditions were optimal for the species (Missouri Natural Heritage Program 2006a). While sink-hole pond habitats in the state have been intensely surveyed, additional searches in appropriate sandy swale habitat in Butler, Clark, Lewis, Mississippi, New Madrid, Pemiscott, Ripley, Scott, and Stoddard counties are warranted. Only one population was located during a search of extant sites in Scott County in August 2006 (McKenzie, pers. obs.). The lack of occurrence at additional sites in 2006 is undoubtedly due to the dry conditions prevailing at the sites.

Nebraska.—Although The Great Plains Flora Association (1977) listed *S. hallii* from nine counties in Nebraska, Schuyler (1969) and Rolfsmeier (1995) determined that the species was historically known only from Holt and Rock counties. Other reported county records for Nebraska were based on misdeterminations of *S. saximontanus* (Rolfsmeier 1995; Schuyler, pers. comm.; S.G. Smith, pers. comm.). In 1999, two populations were discovered in Holt and Brown counties (Steinauer 2001a). Steinauer (2001a) subsequently conducted a survey for *S.hallii* in 2000 and found an additional 18 populations, where plant numbers ranged from 2 to 5,000+.

In 2001, Steinauer (2001b) discovered another four populations of *Schoenoplectus hallii*. Steinauer (2001a, b) established new county records for the species in Garfield, Loup, and Wheeler counties (Table 3). Twenty-seven extant sites of *S. hallii* have been documented in the state within the last 25 years, scattered throughout six counties in the sandhills region of northcental Nebraska (Table 1) (R. Schneider, Nebraska Natural Heritage Program, pers. comm.). Because it has been estimated that there are 19,300 square miles (Knue 1997) of sandy habitat within the sandhills region of the state, ongoing surveys are likely to yield additional new populations of this species (Steinauer 2001a). Further surveys are necessary before the status of this species in the state can be more accurately assessed.

Ohio.—A report that the species occurs in Ohio (NatureServe 2006) is in error.

Oklahoma.—Prior to 2000, there were five reports of *S. hallii* recorded for Oklahoma from Atoka, Comanche, Johnston, and Woods counties (Watson 1993; L.Watson, Oklahoma Biological Survey, pers. comm.; P. Hernandez, pers. comm.; L. Magrath, University of Science and Arts of Oklahoma, pers. comm.). Of these, three have been confirmed by S.G. Smith as *S. hallii*; one each from Atoka, Comanche, and Johnston counties (S.G. Smith, pers. comm.). The others, one from Comanche County and one from Woods County, were determined to be *S. saximontanus* (S.G. Smith, pers. comm.). In 2000, Magrath and refuge staff of the Wichita Mountains Wildlife Refuge conducted surveys for *S. hallii* and *S. saximontanus* at 134 ponds on the refuge (Magrath 2002). *Schoenoplectus hallii* was documented at 14 ponds, *S. saximontanus* at 10, and both species at four ponds. Plants were typically found on ponds that were subject to seasonal drawdowns, and population estimates ranged from one plant to several thousand (Magrath 2002). Despite being documented at 14 ponds, personnel of the Oklahoma Natural Heritage Inventory in Norman consider the Wichita Mountains Wildlife Refuge to have only one site until further examination of the populations on the Refuge can be undertaken (B. Hoagland, pers. comm.).

Magrath (2002) noted the destruction of some populations of *S. hallii* on the refuge by livestock, but acknowledged that such animals may benefit the species by transporting achenes to other sites. In 2001, the sites on the refuge were revisited to assess the status of *S. hallii* and *S. saximontanus*, and the predominance of abnormal and aborted achenes was noted in several plants of both species (Smith et al. 2004). In 2002, specimens of *S. hallii, S. saximontanus* and potential hybrids were collected (Smith et al. 2004) and those with unusual achenes were independently determined by S.G. Smith and Schuyler as the first putative hybrids recorded between *S. hallii* and *S. saximontanus* (Smith et al. 2004).

Further studies on the potential of hybridization of the two species on the Wichita Mountains Wildlife

Refuge are warranted, as the possibility of hybridization (Seehausen 2004) may threaten the continued existence of *S. hallii* in Oklahoma. Additional surveys should be conducted in Oklahoma populations and confirmed sites should be monitored. Until such investigations are conducted and the extent of hybridization is determined, the status of *S. hallii* in Oklahoma will remain unknown.

Oregon.—Koyama (1962) erroneously reported *S. hallii* from Oregon by misreading the label on a collection made by J. Zimmerman (3444) near the small town of Oregon in Dane County, WI (Schuyler 1969).

South Carolina.—Previous reports for this species in South Carolina were based on misdeterminations of *S. erectus* (S.G. Smith, pers. comm.).

South Dakota.—Previously published reports of *S. hallii* in South Dakota are based on misdeterminations of specimens of *S. saximontanus* (S.G. Smith, pers. comm.; Schuyler, pers. comm.).

Texas.—Prior to 2003, it was concurred that all historical records of *S. hallii* for Texas were referable to either *S. erectus* or *S. saximontanus* (S.G. Smith, pers. comm.; Schuyler, pers. comm.). The species was correctly reported in the state in 2003, when it was discovered in Wise County (O'Kennon & McLemore 2004). The species is known to persist at three ponds on the Lyndon B. Johnson National Grasslands between April and December (O'Kennon & McLemore 2004), but it may be present throughout the year (O'Kennon, pers. comm.). O'Kennon & McLemore (2004) noted that *S. hallii* occurred along the margins of sandy clay ponds that have widely fluctuating water levels. They estimated that there were ca. 200 individuals at each of the small ponds, which merge into one site during periods of high water. The site is managed by the Forest Service (O'Kennon & McLemore 2004).

Wisconsin.—*Schoenoplectus hallii* was first collected in Wisconsin in 1950 by J. Zimmerman at Lake Barney in Dane County and it was rediscovered at Lake Barney in 1996 by S.G. Smith and J. Dobberpuhl (S.G. Smith, pers. comm.). There were few plants at this small site in 1996 and they were apparently dwarfed due to grazing by cattle or horses. Without some means of properly managing this site, *S. hallii* is threatened with extirpation (S.G. Smith, pers. comm.). S.G. Smith, with J. Laatsch of the Wisconsin DNR, searched the shore of Lake Barney in 2006 and did not find *S. hallii*, perhaps because of turbid water that obscured much of the shore vegetation (S.G. Smith, pers. comm.).

Previous evaluations by the USFWS

Schoenoplectus hallii was listed as a category 2 candidate species in the USFWS's 1993 Plant Candidate Review for Listing as Endangered or Threatened Species (58 FR 51143-U.S. Fish & Wildlife Service 1993). Category 2 candidate species comprised taxa for which information indicated that a proposal to list as endangered or threatened was possibly appropriate, but for which conclusive data on biological vulnerability and threats were not currently available to support proposed rules. In 1995, the USFWS's Columbia, Missouri Field Office began a status review of *S. hallii* and solicited information from species experts and botanists throughout the range of the species. Data were summarized in an initial range-wide status assessment completed in 1998 (McKenzie 1998).

On 5 Dec 1996, the Director of the USFWS established new policy on the definition of candidate species (formerly category 1) and outlined how the USFWS would consider species for which they remained concerned (formerly category 2 or C2) (61 FR 64481-U.S. Fish and Wildlife Service 1996). Under the new policy, candidates are defined as those species for which the USFWS has on file sufficient information on biological vulnerability and threats to support issuance of a proposed rule to list as endangered or threatened, but issuance of the proposed rule is precluded by other listing actions.

Former C2 species for which the USFWS lacks sufficient information to classify as candidate species will no longer be enumerated on an official list. Nonetheless, other agencies that have developed extensive data bases on former C2 species (e.g., The Nature Conservancy; state natural heritage programs) will continue to monitor these species and maintain communication with the USFWS to help determine when sufficient information is available to warrant their addition to the USFWS's list of candidate species.

Summary of Threats

A. The present or threatened destruction, modification, or curtailment of the species' habitat or range.—Although a clear picture of the overall distribution of *S. hallii* is currently not possible without additional survey work being conducted during years when habitat is suitable, several known populations are subject to a multitude of threats. The greatest threats to Hall's bulrush involve the destruction and/or alteration of its wetland habitat (Ostlie & Gottlieb 1992; Robertson et al. 1994; McKenzie 1998; Penskar & Higman 2003; Beatty et al. 2004; NatureServe 2006). Range-wide, the lowering of water tables, depletion of ground water for irrigation, and changes to the hydrology supporting *S. hallii* habitat may be the most important factors that threaten the continued existence of the species (McKenzie 1998; Steinauer 2001a; Beatty et al. 2004). Any alteration to the hydrology that continually supports this habitat would disrupt the cycles necessary for this species' germination and establishment (Ostlie 1990; Robertson et al. 1994; Steinauer 2001a). Freeman (pers. comm. in Ostlie 1990; Morse, pers. comm.) postulated that groundwater depletion in Kansas may have lowered the water table such that wetland habitat favorable for the species is now being created less often than occurred historically, and Knue (1997) implied that ditching and pumping water from groundwater sources within the Nebraska sandhills for agriculture and domestic livestock may negatively impact wetland habitat. Many records of *S. hallii* for Nebraska are from this region of the state (Rolfsmeier 1995). The depletion of groundwater aquifers has also been identified as a threat to *S. hallii* in Illinois (S. Horn, Illinois TNC, pers. comm.). In Missouri, center-pivot irrigation may be lowering underground aquifers that contribute to flooded conditions in sand prairie swales (Bob Gillespie, Missouri DOC, pers. comm.). The alluvial aquifer in Missouri provides more than 7 billion gal of water per day for row crop agriculture in the area (Kleiss et al., 2000), resulting in a recession of groundwater from the shallow ponds in the region. Smith & Houpis (2004) determined that *S. hallii* did not respond physiologically to drought conditions, but continued to transpire until plants were desiccated. Because of this failure to respond to dry conditions, Smith (2003) concluded that for the species to complete its life cycle, groundwater levels must remain within 1 m of the surface throughout the growing season in Missouri, and Steinauer (2001a) suggested that elevated ground water levels in excess of 1 m above normal water levels were necessary to provide habitat in the Nebraska sandhills.

Schoenoplectus hallii thrives when fluctuating water levels create the temporary, wet habitat that prevents the establishment of competing perennials (Ostlie 1990; Robertson et al. 1994; McClain et al. 1997; Schuyler 1969). Robertson et al. (1994), however, noted that inundation will kill flowering plants of *S. hallii* if rising waters overtop the plants following germination and establishment. Schuyler (pers. comm.) postulated that the permanent inundation of the only known historical site in Massachusetts is responsible for the disappearance of the species there. Schuyler (1969) stated, "It appears that *S. hallii* grows in unstable habitats of sandy substrates, pioneer habitats from the standpoint of plant succession, which are well-suited for the growth of *S. hallii* but few other species of flowering plants. The restriction of *S. hallii* to this kind of unstable sandy pioneer habitat probably accounts for its unusual localized distribution."

The habitat of *S. hallii* is threatened by residential, commercial, agricultural, and recreational development (McClain et al. 1997; McKenzie 1998; Beatty et al. 2004). In Kentucky, the largest portion of the only known site in the state was recently destroyed during activities associated with a new truck stop adjacent to a major highway (D. White, Kentucky State Nature Preserves Commission, pers. comm.). The remaining portion of the site is also threatened from the tillage associated with planting crops (Chester 1988). Although Illinois supports the largest number of populations of *S. hallii* within its range, the species' existence in that state is threatened with the continued and widespread alteration of its habitat for agricultural and residential development (McKenzie 1998; Beatty et al. 2004; NatureServe 2006). The largest populations known for the species in 1995 were destroyed in Illinois due to tillage in 1996 and 1997, when drier conditions enabled farmers to plow wetland habitat (McClain et al. 1997; McKenzie 1998). Some sites in the state are threatened due to the filling of sand ponds for development and agriculture and the drainage of wet sand habitat to increase agricultural production (McClain et al. 1997).

Schoenoplectus hallii in Michigan is subject to threats in the state including dredging and filling operations associated with residential development (Crispin & Penskar 1990), off-road vehicle use and trail bikes, (Ostlie 1990; Penskar & Higman 2003), and the potential alteration of the natural hydrology of wetland habitat by local industries (Crispin & Penskar 1990; Penskar & Higman 2003). The only site in Porter County, IN is also threatened due to heavy recreational use (Homoya, pers. comm.), and Steinauer (2001a) identified ditch maintenance as a potential threat to populations in Nebraska that occur in road-side ditches. Penskar (pers. comm.) noted that one site on private property in Michigan is negatively impacted through shoreline modifications by heavy equipment.

Heavy grazing has been noted at sites in KS, MO, NE and WI, but it is not known whether this type of disturbance negatively impacts the species (Freeman, pers. comm.; Steinauer 2001a; Magrath 2002). Some populations of *S. hallii* are threatened from various chemical contaminants or herbicides. Portions of one of the larger Illinois' populations were destroyed in 1995 due to application of post-emergent herbicides (B. Meyers-Croteau, Illinois State University, pers. comm.). A historical site in Massachusetts was negatively impacted by storm-water runoff, septic effluent, and herbicides that were used to control unwanted species (Sorrie 1987; B. Sorrie, pers. comm., in Ostlie 1990). The application of numerous chemicals associated with agricultural practices throughout the species' range may inhibit achene germination (Rojas-Garciduenas et al. 1962; Kozlowski and Sasaki 1968), seedling development (Eliasson & Palen 1972) and growth (Musarrat & Haseeb 2000), or prevent sexual reproduction (Nartvaranant et al. 2004).

Woody encroachment and the spread of exotic plants have been identified as threats to *S. hallii* in various portions of the species' range (Sorrie 1987; McKenzie 1998; Steinauer 2001a; Beatty et al. 2004; Rolfsmeier & Weedon 2005). It is threatened by late-successional perennials in areas where early to mid-successional habitat is not maintained or regulated (Bowles et al. 1990; Robertson et al.1994). Purple loosestrife (*Lythrum salicaria* L.) was identified as a threat to *S. hallii* in Indiana, Massachusetts and Nebraska (Sorrie 1987; McKenzie 1998; Steinauer 2001a; Beatty et al. 2004; Rolfsmeier & Weedon 2005). Sorrie (pers. comm. in Ostlie 1990) suggested that the establishment of *Lythrum salicaria* at a historical Massachusetts site prevented any reestablishment of *S. hallii* there, and Bowles et al. (1990) asserted that a Lake County, IN site was also threatened by this exotic species. Rolfsmeier & Weedon (2005) noted that leafy spurge (*Euphorbia esula* L.) may be a potential threat to *S. hallii* in the future in Nebraska as this aggressive exotic is near extant sites. The species is also threatened by competition from reed-canary grass (*Phalaris arundinacea* L.) and various buckthorn (*Rhamnus*) species (S.G. Smith, pers. comm.).

An analysis was recently conducted in Missouri that outlined all known threats to sand prairies in the state, which included seven of the ten known *S. hallii* sites. Threats identified that were not discussed above included: 1) changes in ownership that could result in a lack of management, 2) land leveling associated with agricultural and industrial operations that modify or destroy sandy swale habitats, 3) disruption of overland flood events by flood control infrastructures (levees, ditches, berms, etc.), 4) reductions in the frequency of overland flood events necessary to create suitable habitat for germination and plant growth, 5) destruction of sandy habitats due to quarrying for sand or disposal of garbage or refuse, 6) pollution of groundwater or surface waters that support the species, 7) the loss of landowner agreements or management and support capabilities, 8) disinterest of landowners and conservation land managers in the development and implementation of management techniques necessary to maintain the habitat, and 9) the lack of outreach support to the public on the importance of maintaining sandy swale habitat (Gillespie, pers. comm.).

While the distribution of *S. hallii* is not well understood, the threats to many of the populations are of such magnitude that proper maintenance and management of habitat is needed to ensure the continued existence of this species.

B. Over-utilization for commercial, recreational, scientific, or educational purposes.—There is little evidence that this species is being negatively impacted due to over- utilization for commercial, recreation, scientific or educational purposes.

C. Disease or predation.—It has been postulated by S.G. Smith (pers. comm.) that *S. hallii* may be threatened by predation from increasing populations of mute swans (*Cygnus olor*) and Canada geese (*Branta canadensis*). These waterfowl species readily feed on the vegetation and achenes of bulrushes (Martin et al. 1951). In addition, climate models for the Midwest predict that the increasing incidence of extreme weather events will cause an increase in the number of insect pests that damage native vegetation (Rosenzweig et al. 2000).

D. The inadequacy of existing regulatory mechanisms.—*Schoenoplectus hallii* currently has a NatureServe ranking of G2 (globally imperiled because of rarity or some factor(s) making it very vulnerable to extinction or elimination) and is listed as S1 (critically imperiled) in all states where it is considered extant, except for Michigan, Missouri and Nebraska where it is listed as S2 (imperiled) (Missouri Natural Heritage Program 2006b; NatureServe 2006). These rankings, however, do not provide any regulatory protection for *S. hallii* or its habitat.

In some states, *S. hallii* is given special designations separate from the Nature Conservancy ranking. *Schoenoplectus hallii* is listed as endangered in Kentucky (Kentucky State Nature Preserves Commission 2007), a species of special concern in Iowa (Iowa Department of Natural Resources 2007), threatened in Illinois (Herkert & Ebinger 2002; Illinois Endangered Species Protection Board 2007), endangered in Indiana (Indiana Department of Natural Resources 2007), threatened in Michigan (Michigan Department of Natural Resources 2007; Michigan Natural Features Inventory 2007), status unknown in Oklahoma and Texas (Oklahoma Biological Survey 2007; The Nature Conservancy of Texas 2007), and endangered in Wisconsin (Wisconsin Department of Natural Resources 2007).

In Illinois, some protection is provided to any plant species that is state listed by the Illinois Endangered Species Protection Board (2007) following regulations outlined under the Illinois Endangered Species Protection Act (Illinois Department of Natural Resources 2007a; Michigan State University 2007). Under this statute, individuals are prohibited from: 1) taking state listed plants without the expressed written permission of the landowner or 2) selling or offering for sale plants or plant products of endangered species on the Illinois list (Illinois Department of Natural Resources 2007a; Michigan State University 2007). Additionally, consultation is required for any state funded project that could adversely affect state listed species (Illinois Department of Natural Resources 2007b).

Little protection is afforded *S. hallii* under Indiana law, but personnel with the Indiana Department of Natural Resources have an opportunity to provide input on state-funded projects that could negatively impact the species (Homoya, pers. comm.). Endangered or threatened plants can not be taken in Michigan without a permit (Penskar, pers. comm.), as they are protected under the Endangered Species Act 451 of 1994 (Part 365; Michigan Legislature 2007) of Michigan (Michigan Department of Natural Resources 2007; Michigan Natural Features Inventory 2007; Michigan State University 2007).

In Nebraska, *S. hallii* is listed as a Tier 1 At-Risk Species as part of the Nebraska Game and Parks Commission's Natural Legacy Project (Nebraska Game & Parks Commission 2007a). This program is part of the state's development of a Comprehensive Wildlife Strategy that has been initiated in all 50 states (Nebraska Game & Parks Commission 2007b). Nebraska's listing of *S. hallii* as Tier 1 At-Risk Species does not provide any regulatory protection status to the species, but the designation has heightened awareness of the species' management needs and the Nebraska Department of Roads proactively consults with the Nebraska Game and Parks Commission for highway projects that may impact the species (Schneider, pers. comm.). *Schoenoplectus hallii* can not be collected in the state without a permit (Schneider, pers. comm.).

A state listing as endangered provides little protection for *S. hallii* in Wisconsin under state statutes 29.604 and NR(Natural Resources) 27.03-NR27.07 (Wisconsin Legislature 2007a, b; Michigan State University 2007). Under Wisconsin law, the taking of *S. hallii* is prohibited without a permit under section 27.05. Permits are not required, however, for persons who want to take this or other state listed species: 1) on property which they own or lease or for which they have been granted landowner permission, except if the plants or their progeny are sold or processed, 2) on property that is being used for agriculture, construction,

or forestry practices, or 3) on property that is being operated or maintained as a utility facility [Michigan State University 2007; Wisconsin Legislature 2007b- 27.05 (3)].

State endangered species statutes exist for IN, KS, MO, NE, OK, and TX but plants are not covered under state laws for these states. A summary of all state statutes is available at the Animal Legal & Historical Web Center of the Michigan State University College of Law (Michigan State University 2007).

E. Other natural or man-made factors affecting its continued existence.—*Population isolation.*—Because of human modification to the landscape (Robertson et al. 1994; McKenzie 1998; NatureServe 2006), suitable habitat for the species has been reduced to small, isolated transient wetlands. As a result, populations of *S. hallii* are small and often widely separated, some by several hundred miles. Reduction in population size is accompanied by loss of genetic variation, which reduces the ability of the population to adapt to changing environments and increases the risk of extinction (Barrett & Kohn 1991; Newman & Pilson 1997). Ellstrand & Elam (1993) concluded that in small populations, fitness is likely to decrease because of the fixation of deleterious recessive alleles. This was confirmed in a field study of *Lolium multiflorum* Lam., which had reduced vigor and reproductive capacity with decreasing population size (Polans & Allard 1989). The loss of fitness may not become evident until later stages in the species' life cycle. In small populations of *Gilia achilleifolia* Benth., inbreeding depression was expressed as decreased survivorship of seedlings, rather than in seed production or germination (Schoen 1983). Others (Frankel & Soule 1981; Holtsford & Ellstrand 1991) determined that inbreeding depression, and a greater threat of extinction, was higher in populations with an increased rate of selfing. Although the mating system of *S. hallii* has not been studied, the terminal flowers are perfect and have the potential for self fertilization. This subject warrants further study.

Loss of seed bank integrity.—While populations of *S. hallii* are frequently isolated, in years optimal for germination, they may be extremely large, presumably due to the regeneration of the population from a persistent seed bank (McClain et al. 1997). A large, persistent seed bank, however, does not necessarily result in a restoration of the genetic variation or the vigor of the original population. Wienhold and van der Valk (1989) determined that the number and density of seeds in a seed bank decreases after 10 or more years when wetlands are drained for extended periods. It is likely that the same losses apply to habitats occupied by *S. hallii* during extended dry years and that such declines are accelerated by such agricultural practices as plowing, disking, or harrowing that damage seeds in the soil (Smith 2001).

It is generally accepted that older seeds have reduced viability (Roberts 1973) and increased chromosome breakage and gene mutation (Murata et al. 1982; Murata et al. 1984). Levin (1990) maintained that genetic and chromosomal changes associated with a long-lived seed bank provide novel genetic variation for the evolution of a species and are inherently beneficial. Others disagree with this assessment (e.g., Hamilton 1994) and empirical evidence is inclusive. Mean heterozygosity among plants derived from the seed bank was lower than that existing in surface plants of *Lesquerella fendleri* (A. Gray) S. Wats. (Cabin et al. 1998), while in *Clarkia springvillensis* Vasek, it was concluded that the seed bank could act as a buffer against the small population effect by supplying plants with greater heterozygosity than that existing in the aboveground population (McCue & Holtsford 1998). Populations regenerated from a seed bank sometimes show evidence of inbreeding depression and a decline in performance of seedlings. After restoration of a population of *Nymphoides peltata* (Gmelin) O. Kuntze from a seed bank, Takagawa et al. (2006) reported that there was a negative effect of inbreeding depression and noted that genetic variation and growth performance of seedlings derived from the seed bank were significantly reduced. It is, therefore, important to examine genetic makeup and chromosomal damage and their effects on survival and genetic composition of populations of *S. hallii*, as well as the longevity of seeds in the soil, before it can be assumed that the seed bank is representative of a viable population.

Hybridization.—A threat of hybridization between *S. hallii* and *S. saximontanus* exists in Oklahoma (Smith et al. 2004) and one site in Kansas where the two species are sympatric (Freeman, pers. comm. 2006). Smith (2002b) also reported that a specimen taken from the coastal plain of Georgia was intermediate between *S.*

hallii and *S. erectus*. It is not known if anthropogenic practices have potentially altered the distribution of *S. hallii* in relation to its closely related congeners. Magrath (2002) noted that *S. hallii* and *S. saximontanus* co-occurred at four ponds on the Wichita Mountains Refuge and Smith et al. (2004) reported the first putative hybrids between the two species from material collected on the refuge. Although *S. hallii* and *S. saximontanus* were documented in 1997 from the same locality in Harper County, KS, a cursory examination of specimens of both species from the locality indicated no evidence of hybridization (Freeman, pers. comm. 2006). A more organized and thorough examination of individuals in the population at this locality may also reveal the presence of hybrids as occurred in Oklahoma (Smith et al. 2004). Because waterfowl are known dispersal agents for various sedges, including *S. hallii* (Dunn & Knauer 1975; McClain et al. 1997; Beatty et al. 2004), it is possible that the management of various wetlands/impoundments for waterfowl may increase the potential of *S. hallii* mixing with its more common congeners, *S. saximontanus* and *S. erectus*.

According to conservation geneticists, hybridization poses a serious threat to the survival of a rare species that hybridizes with a closely related congener (Levin et al. 1996). Although the extinction of rare species typically is attributed to systematic environmental change that renders the habitat unsuitable (Harrison 1991; National Research Council 1995), hybridization may have a profound effect on the persistence of a species (Rieseberg 1991; Ellstrand 1992; Rieseberg & Linder 1999).

Hybridization promotes the extinction of rare species by reducing the potential for plants to replace themselves, thereby inhibiting the growth of their populations—the lower the rate of growth, the greater the potential for extinction in a variable environment (Menges 1992). Hybridization may reduce a population's growth rate by adversely affecting its reproductive effectiveness, its competitive status and its interactions with herbivores (Levin et al. 1996).

The growth rate of a population may be retarded by the production of hybrid seed, which is produced in place of the rare species, i.e., resources are limited and an investment in hybrid seed reduces the amount of energy that can be allocated to conspecific seed. The outcome is the same whether the hybrid seeds abort or are viable. When hybrid seeds are produced by both a rare species and its abundant congener, a numerically small population will produce a higher percentage of hybrid seed than the more numerous related species when the two are intermixed (Felber 1991; Levin et al. 1996). Species have a number of defenses against interbreeding; however, closely related congeners often have weaker barriers to hybridization and a greater minority disadvantage (Levin et al. 1996).

The numerical disadvantage of a rare species is compounded by the proliferation of fertile hybrids. The addition of these plants to a population containing two related plants decreases the proportional representation of the rare species. In time, this backcrossing can result in the assimilation of the rare species whose genetic identity will become extinct (Rhymer & Simberloff 1996). Over evolutionary time, the DNA of the former rare species may be lost from the gene pool altogether (Rieseberg et al. 1996).

Climate change.—*Schoenoplectus hallii* can disappear from sites during periods of drought, only to reappear when flooded conditions exist (Robertson et al. 1994; McClain et al. 1997; Penskar & Higman 2003; McKenzie 1998; Beatty et al. 2004). Global warming and climate change could contribute to loss of wetland habitat required by this species by causing droughts to be more extensive and persistent, especially in the Midwest where drought conditions have persisted for several years, and are predicted to continue with increasing frequency in the future (Hansen 1989; Rosenzweig et al. 2000). Climate models indicate that high temperatures and an increase in pests (Rosenzweig et al. 2000) and other invasive species (Vitousek 1994) will accompany the increased frequency of droughts and other extreme events (Dai et al 1996). Global warming and climate change have increasingly been identified as factors which may contribute to the loss of biodiversity and extinction of imperiled species (Wilcove et al. 1998; Thomas et al. 2004; Maschinski et al. 2006), but only Beatty et al. (2004) have addressed the issue for *S. hallii*.

Changes in crop production and ethanol demand.—Habitat for *S. hallii* is threatened due to projected changes in agricultural development, especially corn production that is needed for increasing demands for ethanol production (Keeney and Mueller 2006; U.S. Department of Agriculture 2007). Keeney and Mueller

(2006) estimated a 254% increase in volume of water used in ethanol production from 1998 to 2008 for only one state in the Midwest. Corn production for ethanol plants is projected to increase in 2007 by 14.2% in Illinois (U.S. Department of Agriculture 2007), the state with largest number of extant sites for *S. hallii* (Table 1). Nebraska has the second largest number of extant sites for the species (Table 1) and large areas of unsurveyed habitat, but Keeney and Mueller (2006) postulated that increasing demand for ethanol production may result in competing water uses in that state. Increased demands for water from above ground sources and underground aquifers could prevent the formation of important wetland habitat needed by *S. hallii* throughout the Midwest.

Ownership, current protective status, habitat protections or management

Few of the extant sites of *S. hallii* in the United States receive protective status and only a small percentage of sites documented within the last 25 years are actively managed to maintain habitat for the species. Of the 84 sites recorded for the species within the last 25 years, approximately 16 (~ 19%) are under public ownership. The remaining 81% are privately owned, which could make them potentially vulnerable to habitat change that may threaten the species at these sites. The only known sites in Kansas and Kentucky are under private ownership, as are the majority of sites in Illinois, Missouri and Nebraska. The existence of *S. hallii* populations on public land, however, does not guarantee that the habitat will be properly managed and maintained to ensure the persistence of the species. The *S. hallii* site at Horseshoe Lake Conservation Area in Illinois is also under public ownership, but there is no management plan for the species (McClain, pers. comm. 1996).

Schoenoplectus hallii is protected and actively managed at four of the five sites in Michigan. Two sites on the Allegan State Game Area are under the jurisdiction of the Wildlife Division of the Michigan DNR. They are protected by barriers that control access, and are regularly patrolled and managed (Penskar, pers. comm. 2006). One site in Muskegon County is located within a dedicated Research Natural Area on the USFS's Huron-Manistee National Forest, and a second site is protected as part of a nature preserve owned by the Michigan Nature Association (Penskar, pers. comm. 2006). Three sites at the Indiana Dunes National Lakeshore are owned by the National Park Service; however, Bowles et al. (1990) reported that at least one site is threatened by succession and the spread of purple loosestrife.

The one site for *S. hallii* in Oklahoma is on a USFWS Wildlife Refuge, but the species is not covered under a management plan (C. Kimball, Wichita Mountains Wildlife Refuge, pers. comm.). Specific management actions may be included for the species when the refuge develops a 15-year Comprehensive Conservation Plan (CCP) (Kimball, pers. comm.), but the initiation of such a plan has not yet been scheduled (U.S. Fish & Wildlife Service 2007).

Two of the sinkhole pond sites in Howell County, MO are registered under the Nature Conservancy's Registry Program (T. Smith, pers. comm.), but the program is not regularly maintained (D. Ladd, Missouri TNC, pers. comm.). Landowner agreements that exist for two sites in Scott County, MO will likely maintain habitat for the species into the foreseeable future, but continued support for the agreement is unpredictable if there is a change in ownership (Gillespie, pers. comm.).

In Nebraska, two sites (South Pine WMA and Twin Lakes WMA) are on public land, but one of the sites is within a few miles of a population of purple loosestrife (Steinauer 2001a). The listing of *S. hallii* as a Tier 1 At-Risk Species will ensure that it is a priority for conservation efforts and a focus for various management plans (Schneider, pers. comm.; Nebraska Game & Parks Commission 2007c).

The only known *S. hallii* site in Wisconsin is on prison grounds, which is under public ownership, but the site has limited access (Anderson, pers. comm.). There is no management plan in place to benefit the species at this site (Anderson, pers. comm.).

The only known site in Texas is on the Lyndon B. Johnson National Grasslands, but no information on management actions for the species was identified by O'Kennon and McLemore (2004).

Management actions needed

While the management of *S. hallii* sites is probably necessary for its continued existence, the success of such

efforts may be difficult due to the specific habitat requirements for this wetland-adapted plant (Bowles et al. 1990). Ostlie (1990) recommended that extant sites of the species should be protected from human disturbance and that the hydrological cycles necessary for the creation and maintenance of its habitat should be preserved. Robertson et al. (1994) suggested that the acquisition of extant sites should be a priority. In areas where land acquisition is not feasible, easements that incorporate various management agreements may be the best approach for maintaining and protecting *S. hallii* habitat. The Nature Conservancy's Registry Program could be an efficient method of managing populations on private land, but the lack of active participation due to limitations in time and personnel will limit the usefulness of the program. Various state-initiated landowner contact programs may also be helpful in managing the species over a long-term basis such as the Landowner Incentive Program (LIP) implemented in many states. The USFWS's Partners for Fish and Wildlife Program could be helpful in assisting landowners in the management of *S. hallii* on private land. Perhaps the greatest potential for managing habitat to benefit the species will be through the development and implementation of each state's comprehensive wildlife strategy similar to the one in Nebraska (Nebraska Game & Parks Commission 2007b).

Management plans should be developed for the few sites that are publicly owned. Such plans should include the following recommendations: 1) protect and maintain the hydrology essential to the species, 2) retard plant succession, 3) control competing perennials, especially aggressive exotics, 4) control off-road vehicle use, 5) develop active public outreach and education programs, and 6) support the development of long- term monitoring programs and active research on the species.

Research needs

Additional research on the life history and ecological requirements of *S. hallii*, as undertaken by Baskin et al. (2003), Penskar & Higman (2003), Smith (2001, 2002a, 2003), Smith & Houpis (2004), Smith et al. (2006), and as identified by Beatty et al. (2004), are needed to better understand the population dynamics of this species. Investigations that compare reproduction from achenes versus perennial growth from the species' short rhizomes need to be undertaken. Although initial germination and life history dynamics for terminal achenes have been established (Baskin et al. 2003; Penskar & Higman 2003; Smith 2001, 2002a, 2003; Smith et al. 2006), further research is warranted to more clearly pinpoint the environmental factors necessary for germination and establishment of *S. hallii* achenes. The role of amphicarpy in the life history of the species needs evaluation, including studies of the mating systems of both terminal and basal florets. Additional research should be initiated to determine the relationship of wetland hydrology to the population dynamics of *S. hallii*, especially the role of surface flooding and underground aquifers and groundwater in the creation of habitat for the species. Studies to identify the dispersal mechanisms that enable the species to colonize new areas would be valuable. The germination of achenes of *Schoenoplectus* spp. can apparently be enhanced when they pass through the digestive tracts of birds (deVlaming & Proctor 1968; Powers et al. 1978; Kantud 1996). Similar studies involving the achenes of *S. hallii* should be initiated to determine if birds help facilitate dispersal of this species.

Examinations of additional specimens are necessary to clarify the historical and current distribution of the species (e.g., specimens from GA, IA, and OK) (S.G. Smith, pers. comm.). Additional surveys are necessary to better delineate the range of *S. hallii*, provided they are conducted during years when habitat conditions are favorable to the species and specimens can be examined by experts who can accurately distinguish the species from its close relatives. An examination of precipitation patterns may be useful in predicting what years the species is more likely to emerge. Voucher specimens should be confirmed by either S.G. Smith or Ernie Schuyler. The communities and ecological associates that occur with *S. hallii* should be further characterized, which will enable researchers in the future to develop adequate search-images for the species.

Studies should be initiated that examine the effects of grazing, controlled burning and other types of disturbance (e.g., off-road vehicle use, trail bikes, burning, mowing, disking) on the species. Population genetics studies need to be conducted to determine the amount of variation and gene flow within and among populations. Studies of the population and genetic consequences of recruitment from a long-lived seed

bank need to be conducted to clarify the current definition of "extant sites" as represented by the presence of achenes in the soil. Monitoring efforts need to be initiated for all extant populations, especially those populations that appear annually and are not as cyclic in their occurrence as at other sites within the species' range. The report of a putative hybrid between *S. hallii* and *S. saximontanus* at the Wichita Mountains Wildlife Refuge in Oklahoma (Smith et al. 2004) suggests that hybridization is a threat at sites where conspecifics are sympatric. Thus, further investigations that examine the extent of hybridization at Oklahoma and Kansas sites should be initiated to determine if *S. hallii* is threatened from genetic swamping or genetic dilution. *Schoenoplectus hallii* would benefit from additional seed viability studies and from research that examines genetic differences between and among populations. Finally, the impacts of global warming and climate change on the loss of wetland habitat for the species should be evaluated by conducting studies similar to analyses for other species (e.g., Hannah et al. 2002; Pearson & Dawson 2003) and incorporating the results into long-term management plans.

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REFERENCES

Barrett, S.C.H. and J.R.K. Kohn.1991. Genetic and evolutionary consequences of small population size in plants: implications for conservation. In: D.A. Falk and K. Holsinger eds. Genetics and conservation of rare plants. Oxford Univ. Press, New York. Pp. 3–31.

Baskin, C.C., J.M. Baskin, and E.W. Chester. 2000. Effect of flooding on the annual dormancy cycle and on germination of seeds of the summer annual *Schoenoplectus purshianus* (Cyperaceae). Aquatic Bot. 67:109–116.

Baskin, C.C., J.M. Baskin, E.W. Chester, and M. Smith. 2003. Ethylene as a possible cue for seed germination of *Schoenoplectus hallii* (Cyperaceae), a rare summer annual of occasionally flooded sites. Amer. J. of Bot. 90:620–627.

Beatty, B.L., W.F. Jennings, and R.C. Rawlinson. 2004. *Schoenoplectus hallii* (Gray) S.G. Sm. (Hall's bulrush): a technical conservation assessment. Prepared for the USDA Forest Service, Rock Mountain Region, Species Conservation Report. Peer review administered by Center for Plant Conservation, St. Louis, Missouri.

Beetle, A.A. 1947. *Scirpus*. N. Amer. Flora 18(8):481–504.

Bowles, M.L., M.M. DeMauro, N. Pavlovic, and R.D. Hiebert. 1990. Effects of anthropogenic disturbances on endangered and threatened plants at the Indiana Dunes National Seashore. Nat. Areas J. 10:187–200.

Brodowicz, W. 1990. Noteworthy collections. *Scirpus hallii* A. Gray. Michigan Botanist 29:31.

Browning, J. 1992. Hypogynous bristles and scales in basal florets in amphicarpous *Schoenoplectus* species (Cyperaceae). Nordic J. Bot. 12:171–175.

Bruhl, J.J. 1994. Amphicarpy in the Cyperacae, with novel variation in the wetland sedge *Eleocharis caespitosissma*. Austral. J. Bot. 42:441–448.

Cabin, R.J., R.J. Mitchell, and D.L. Mitchell. 1998. Do surface plant and soil seed bank populations differ genetically? A multipopulation study of the desert mustard *Lesquerella fendleri* (Brasicaceae). Amer. J. Bot. 85:1098–1109.

Chester, E.W. 1988. An unusual habitat type for three rare Kentucky plants. Abstract. Trans. Kentucky Acad. Sci. 49(102):56.

Correll, D.S. and M.C. Johnston. 1970. Manual of the vascular plants of Texas. Texas Research Foundation, Renner.

Crispin, S. and M. Penskar. 1990. *Scirpus hallii* Gray (Hall's bulrush). Unpubl. abstract, Michigan Natural Features Inventory, endangered species manual.

Dai, A., I.Y. Fung, and A.D. Del Genio. 1996. Surface observed global land precipitation variations during 1900–1988. J. Climate 10:2943–2962.

Davidson, R.S. 1959. The vascular flora of southeastern Iowa: Univ. Iowa Stud. Nat. Hist. 20(2):1–102.

deVlaming, V. and V.W. Proctor. 1968. Dispersal of aquatic organisms: viability of seeds recovered from the droppings of captive killdeer and mallard ducks. Amer. J. Bot. 55:20–26.

Dunn, D.B. and D.F. Knauer. 1975. Plant introductions by waterfowl to Mingo National Wildlife Refuge, Missouri. Trans. Missouri. Acad. Sci. 9:27–28.

Eliasson, L. and K. Palen. 1972. Effect of light on the response of pea seedling roots to 2,4–D. Physiol. Pl. 26: 206–209.

Elstrand, N.C. 1992. Gene flow by pollen: implications for plant conservation genetics. Oikos 63:77–93.

Ellstrand, N. and D. Elam. 1993. Population genetic consequences of small population size: implications for plant conservation. Ann. Rev. Ecol. Syst. 24:217–242.

Felber, F. 1991. Establishment of a tetraploid cytotype in a diploid population: effect of the relative fitness of the cytotypes. J. Evol. Biol. 4:195–204.

Flora of North America Editorial Committee, eds. 2002. Vol. 2. Magnoliophyta: Commelinidae (in part): Cyperaceae. Oxford University Press, New York.

Frankel, O.H. and M.E. Soule. 1981. Conservation and evolution. Cambridge University Press. Cambridge.

Gleason, H.A. and A. Cronquist.1991. Manual of vascular plants of northeastern United States and adjacent Canada, ed. 2. New York Botanical Garden, Bronx.

Gray, A. 1863. Manual of botany of the northern United States. Third edition. New York.

Great Plains Flora Association. 1977. Atlas of the flora of the Great Plains; R.L. McGregor, Coordinator; T.M. Barkley, ed. Iowa State University Press, Ames.

Great Plains Flora Association. 1986. Flora of the Great Plains; R.L. McGregor, Coordinator; T.M. Barkley, R.E. Brooks, and E.K. Schofield, eds. University Press of Kansas, Lawrence.

Guldner, L.F. 1960. The vascular plants of Scott and Muscatine counties. Davenport Mus. Publ. Bot. No. 1.

Hamilton. M.B. 1994. Ex situ conservation of wild plant species: time to reassess the genetic assumptions and implications of seed banks. Conserv. Biol. 8:39–49.

Hannah, L., G.F. Midgley, and D. Miller. 2002. Climate change-integrated conservation strategies. Global Ecol. Biogeogr. 11:485–495.

Hansen, J.E. 1989. The greenhouse effect: Impacts on current global temperature and regional precipitation. In: The challenge of global warming. Island Press, Washington, DC. Pp. 35–43.

Harrington, H.D. 1954. Manual of the plants of Colorado. Sage Books, Denver, CO.

Harrison, S. 1991. Local extinction in a metapopulation context: an empirical evaluation. Biol. J. Linnean Soc. 42:73–88.

Herkert, J.R. and J.E. Ebinger. 2002. Endangered and threatened species of Illinois: status and distribution. Vol. 1. Plants. Illinois Endangered Species Protection Board, Springfield.

Hickman, J.C. 1993. Ed. The Jepson manual: higher plants of California. University of California Press, Berkeley.

Holtsford, T.P. and N.C. Ellstrand. 1991. Inbreeding effects in *Clarkia tembloriensis* populations with different natural outcrossing rates. Evolution 44:2031–2046.

Illinois Endangered Species Protection Board. 2007. 2006 endangered and threatened species list. Springfield. http://www.dnr.state.il.us/espb/datelist.htm. Accessed Jan 2007.

Illinois Department of Natural Resources 2007a. Illinois Endangered Species Board.Wildlife- 520 Illinois Compiled Statute (ILCS) 10/Illinois Endangered Species Protection Act. Springfield. http://www.ilga.gov/legislation/ilcs/ilcs3.asp?ActID=1730&ChapAct=520%26nbsp%3BILCS%26nbsp%3B10%2F&ChapterID=43&ChapterName=WILDLIFE&ActName=Illinois+Endangered+Species+Protection+Act%2E. Accessed Apr 2007.

Illinois Department of Natural Resources 2007b. Consultation requirements associated with the Illinois Endangered Species Protection Act. Springfield. http://dnr.state.il.us/orep/nrrc/brief.htm. Accessed Apr 2007.

Indiana Department of Natural Resources 2007. Endangered, threatened, rare and extirpated plants of Indiana. Indianapolis. http://www.in.gov/dnr/naturepr/endanger/etrplants.pdf. Accessed Jan 2007.

Iowa Department of Natural Resources. 2007. Threatened and endangered species. DesMonies. http://www.iowadnr.com/other/files/chapter77.pdf. Accessed Jan 2007.

Kantud, H.A. 1996. The alkali (*Scirpus maritimus* L.) and saltmarsh (*S. robustus* Pursh) bulrushes: a literature review. National Biological Service, Information and Technology Report 6. Jamestown, North Dakota. Northern Prairie Wildlife Research Center web database. Available at http://npwrclib.cr.usgs.gov/starweb/pubsearch/servlet.starweb. Accessed Sep 2006.

Keeney, D. and M. Muller. 2006. Water use by ethanol plants: potential challenges. Institute for Agriculture and Trade Policy. Minneapolis, Minnesota.

Kentucky State Nature Preserves Commission. 2007. Kentucky rare plant database. http://eppcapps.ky.gov/nprare-plants/details.aspx?species=Schoenoplectus%20hallii. Accessed Jan 2007.

Kleiss, B.A., R.H. Coupe, G.J. Gonthier, and B.G. Justus. 2000. Water quality in the Mississippi embayment, Mississippi, Louisiana, Arkansas, Missouri, Tennessee and Kentucky from 1995–1998. Circular 1208, U.S. Geological Survey, Denver.

Knue, J. 1997. Nebraskaland magazine wildlife viewing guide. Nebraskaland Mag. 75(1):1–96. Nebraska Game and Parks Commission, Lincoln.

Koyama, T. 1962. The genus *Scirpus* Linn. Some North American aphylloid species. Canad. J. Bot. 40:913–937.

Kozlowski, T.T. and S. Sasaki. 1968. Germination and morphology of red pine seeds and seedlings in contact with EPTC, CDEC, CDAA, 2,4-D and Picloram. Amer. Soc. Hort. Sci. 193:655–662.

Levin, D.A. 1990. The seed bank as a source of genetic novelty in plants. Amer. Nat. 135:563–572.

Levin, D.A., J. Francisco-Ortega, and R.K. Jansen. 1996. Hybridization and the extinction of rare plant species. Conserv. Biol. 10:10–16.

Magrath, L.K. 2002. *Schoenoplectus hallii* and *S. saximontanus*. 2000 Wichita Mountain Wildlife Refuge survey. Oklahoma Native Pl. Rec. 2(1):54–62.

Martin, A.C., H.S. Zim, and A.L. Nelson. 1951. American wildlife & plants: A guide to wildlife food habits. Dover Publ., New York.

Maschinski, J., J.E. Baggs, P.F. Quintana-Ascencio, and E.S. Menges. 2006. Using population viability analysis to predict the effects of climate change on the extinction risk of an endangered limestone endemic shrub, Arizona cliffrose. Conserv. Biol. 20:218–228.

McClain, W.E., R.D. McClain, and J.E. Ebinger. 1997. Flora of temporary sand ponds in Cass and Mason counties, Illinois. Castanea 62:65–73.

McCue, K.A. and T.P. Holtsford. 1998. Seed bank influences on genetic diversity in the rare annual *Clarkia springvillensis* (Onagraceae). Amer. J. Bot. 85:30–36.

McKenzie, P.M. 1998. Hall's bulrush (*Schoenoplectus hallii*) status assessment. Unpublished report to the U.S. Fish & Wildlife Service, Columbia, MO.

Menges, E.S. 1992. Stochastic modeling of extinction in plant populations. In: Fiedler and Jain, eds. Conservation Biology Chapman and Hall, New York. Pp. 253–275.

Michigan Department of Natural Resources. 2007. Wildlife Division- endangered and threatened species. Rule 99.1028. Plants. Lansing. http://www.state.mi.us/orr/emi/admincode.asp?AdminCode=Single&Admin_Num=29901021&Dpt=NR&RngHigh. Accessed Apr 2007.

Michigan Legislature. 2007. Natural Resources and Environmental Protection Act 451 of 1994. Part 365. Endangered species protection. Sections 324.36501–36507. Lansing. http://www.legislature.mi.gov/(S(jppkk3m3hgmug345wl1pedq5))/mileg.aspx?page=getobject&objectname=mcl-451-1994-iii-1-endangered-species-365. Accessed Apr 2007.

Michigan Natural Features Inventory. 2007. Michigan's special plants. Lansing. http://web4.msue.msu.edu/mnfi/data/specialplants.cfm. Accessed Apr 2007.

Michigan State University. 2007. Animal Legal & Historical Web Center. Statutes and Laws. East Lansing, MI. http://www.animallaw.info/statutes/stusmi324_365.htm. Accessed Apr 2007.

Missouri Natural Heritage Program 2006a. Missouri species and communities of conservation concern database. Missouri Department of Conservation. Jefferson City.

Missouri Natural Heritage Program 2006b. Missouri species and communities of conservation concern checklist. Missouri Department of Conservation. Jefferson City.

Mohlenbrock, R.H. 1976. The illustrated flora of Illinois: Sedges–*Cyperus* to *Scleria*. Southern Illinois University Pres., Carbondale and Edwardsville.

Mohlenbrock, R.H. and D.M. Ladd. 1978. Distribution of Illinois vascular plants. Southern Illinois University Press, Carbondale.

Murata, M., T. Tsuchiya, and E.E. Roos. 1982. Chromosomal damage induced by artificial seed aging in barley. II. Types of chromosomal aberrations at first mitosis. Bot. Gaz. 1413:111–116.

Murata, M., T. Tsuchiya, and E.E. Roos. 1984. Chromosomal damage induced by artificial seed aging in barley behavior of chromosomal aberrations during plant growth. Theor. Appl. Genet. 67:161–170.

Musarrat, J. and A. Haseeb. 2000. Agrichemicals as antagonist of lectin-mediated Rhizobium-legume symbiosis: paradigms and prospects. Current Sci. 78:793–797.

Nartvaranant, P.S. Hamill, J. Leonardi, A.W. Whiley and S. Subhadrabandhu. 2004. Seasonal effects of foliar application of phosphonate on phosphonate translocation, in vitro pollen viability and pollen germination in Hass avocado (*Persea americana* Mill.). J. Hort. Sci. Biotech. 79:91–96.

National Research Council. 1995. Science and the endangered species act. National Academy Press, Washington, DC.

NatureServe. 2006. NatureServe Explorer: An online encyclopedia of life [web application]. Version 5.0 NatureServe, Arlington, Virginia. Available at: http://www.natureserve.org/explorer. Accessed Sep 2006.

Nebraska Game and Parks Commission. 2007a. The Natural Legacy Project: a blueprint for conserving wildlife and their habitats. Appendix 8: Tier 1 At-Risk Species. Lincoln. http://www.ngpc.state.ne.us/wildlife/programs/legacy/pdfs/appendix8.pdf. Accessed Jan 2007.

Nebraska Game and Parks Commission. 2007b. The Natural Legacy Project: a blueprint for conserving wildlife and their habitats. Lincoln. http://www.ngpc.state.ne.us/wildlife/programs/legacy/about.asp. Accessed Jan 2007.

Nebraska Game and Parks Commission. 2007c. The Natural Legacy Project: a blueprint for conserving wildlife and their habitats. Chapter 3: Methodology: identifying ecological communities, at-risk species and biologically unique landscapes. Lincoln. http://www.ngpc.state.ne.us/wildlife/programs/legacy/pdfs/chpater3.pdf. Accessed Jan 2007.

Newman, D. and D. Pilson. 1997. Increased probability of extinction due to decreased genetic effective population size: experimental populations of *Clarkia pulchella*. Evolution 51:354–362.

O'Kennon, R.J. and C. McLemore. 2004. *Schoenoplectus hallii* (Cyperaceae), a globally threatened species new for Texas. Sida 21:1201–1204.

Oklahoma Biological Survey. 2007. Oklahoma Natural Heritage Inventory: Rare and vulnerable plant species of Oklahoma. Norman. http://www.oknaturalheritage.ou.edu/scirpus_hal.htm#distribution. Accessed Jan 2007.

Ostlie, W.R. 1990. The Nature Conservancy's element stewardship abstract for *Scirpus hallii*–Hall's bulrush. Arlington, Virginia.

Ostlie, W.R. and S. Gottlieb. 1992. The Nature Conservancy's element global ranking form for *Scirpus hallii*.

Pearson, R.G. and T.P. Dawson. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope modes useful? Global Ecol. Biogeogr. 12:361–371.

Penskar, M.R. and P.J. Higman. 2003. Hall's bulrush habitat characterization and monitoring project: 1999–2002 Report. Region 3 of the U.S. Fish & Wildlife Service Section 6 Endangered Species Grant Report No. 2003-26. Michigan Natural Features Inventory. Lansing, MI.

Polans, N.O. and R.W. Allard. 1989. An experimental evaluation of the recovery potential of ryegrass populations from genetic stress resulting from restriction of population size. Evolution 43:1320–1323.

Powers, K.D., R.E. Noble, and R.H. Chabreck. 1978. Seed distribution by waterfowl in southwestern Louisiana. J. Wildlife Managem. 42:598–605.

Radford, A.E., H.E. Ahles, and C.R. Bell. 1964. Manual of the vascular flora of the Carolinas. University of North Carolina Press, Chapel Hill.

Raynal, J. 1976. Notes Cyperologiques: 26. Le Genre *Schoenoplectus* II. L'amphicarpie et la sect. L'amphicarie et la sect. *Supini*. Adansonia, ser. 2, 16:119–155.

Reed, P.E. Jr. 1988. National list of plants that occur in wetlands: national summary. U.S. Fish & Wildlife Service Biol. Rep. 88(24):1–244. Washington, D.C.

Rhymer, J.M. and D. Simberloff. 1996. Extinction by hybridization and introgression. Ann. Rev. Ecol. Syst. 27: 83–109.

Rieseberg, L.H. 1991. Hybridization in rare plants: insights from case studies in *Cerocarpus* and *Helianthus*. In: Genetics and conservation of rare plants. D.A. Falk and K.E. Holsinger, eds. Oxford University Press, NY. Pp. 171–181.

Rieseberg, L.H. and C.R. Linder. 1999. Hybrid classification: insights from genetic map-based studies of experimental hybrids. Ecology 80:361–370.

Rieseberg, L.H., B. Sinervo, C.R. Linder, M.C. Ungerer, and D.M. Arias. 1996. Role of gene interations in hybrid speciation: evidence from ancient and experimental hybrids. Science 272:741–745.

Roberts, E.H. 1973. Loss of seed viability: chromosomal and genetical aspects. Seed Sci. Tech. 1:515–527.

Robertson, K.R., L.R. Phillippe, and S.M. Gehlhausen. 1994. The current status of *Scirpus hallii* A. Gray, Hall's bulrush, in Illinois. Illinois Dept. of Conservation Report, Springfield.

Rojas-Garciduenas, M., M.A. Ruiz, and J. Carillo. 1962. Effect of 2,4-D and MCPA on germination and early growth. Weed Sci. 10:69–71.

Rolfsmeier, S.B. 1995. Keys and distributional maps for Nebraska Cyperaceae, Part 1: *Bulbostylis, Cyperus, Dulichium, Eleocharis, Eriophorum, Fimbristylis, Fuirena, Lipocarpha,* and *Scirpus*. Trans. Nebraska Acad. Sci. 22:27–42.

Rolfsmeier, S.B. and R.R. Weedon. 2005. A survey of potential habitat for western prairie fringed orchid (*Platanthera praeclara*) along U.S. Highway 20 from Long Pine to Ewing, NE. High Plains Herbarium unpub. Rep., Chadron, NE.

Roosa, D.M., M.J. Leoschke, and L.J. Eilers. 1989. Distribution of Iowa's endangered and threatened vascular plants. Iowa Dept. of Nat. Res., Des Moines.

Rosenzweig, C., A. Iglesias, X.B. Yang, P.R. Epstein, and E. Chivian. 2000. Climate change and U.S. Agriculture: the impacts of warming and extreme weather events on productivity, plant diseases and pests. Center for Health and the Global Environment, Harvard Medical School, Boston, MA.

Schoen, D.J. 1983. Relative fitness of selfed and outcrossed progeny in *Gilia achilleifolia* (Polemoniaceae). Evolution 37:292–301.

Schuyler, A.E. 1969. Three new species of *Scirpus* (Cyperaceae) in the southern United States. Notul. Nat. Acad. Nat. Sci. Philadelphia 423:1–12.

Seehausen, O. 2004. Hybridization and adaptive radiation. Trends Ecol. Evol. 19:198–207.

Small, J.K. 1972. Manual of the southeastern flora. Hafner Publ. Co., New York.

Smith, M. 2001. An assessment of the biological and ecological requirements of *Schoenoplectus hallii* (Hall's bulrush) population in Scott County, Missouri. Region 3 of the U.S. Fish & Wildlife Service Section 6 Endangered Species Grant. First Year Progress Report. Submitted to the Missouri Department of Conservation, Jefferson City.

Smith, M. 2002a. An assessment of the biological and ecological requirements of *Schoenoplectus hallii* (Hall's bulrush) population in Scott County, Missouri. Region 3 of the U.S. Fish & Wildlife Service Section 6 Endangered Species Grant Second Year Progress Report. Submitted to the Missouri Department of Conservation, Jefferson City.

Smith, M. 2003. An assessment of the biological and ecological requirements of *Schoenoplectus hallii* (Hall's bulrush) population in Scott County, Missouri. Region 3 of the U.S. Fish & Wildlife Service Section 6 Endangered Species Grant. Final Report. Submitted to the Missouri Department of Conservation, Jefferson City.

Smith, M. and J.L.J. Houpis. 2004. Gas exchange responses of the wetland plant *Schoenoplectus hallii* to irradiance and vapor pressure deficit. Aquat. Bot. 79:267–275.

Smith, M., S. Ammann, N. Parker, and P. Mettler-Cherry. 2006. A quantitative study of styles and achenes of terminal and basal flowers of *Schoenoplectus hallii*, a rare plant species of transient wetland habitats. Sida 22:1159–1173.

Smith, M., P. McKenzie, P. Mettler-Cherry, and G. Smith. 2004. A putative hybrid of *Schoenoplectus saximontanus* and *S. hallii* (Cyperaceae) from Oklahoma. Sida 21:475–479.

Smith, S.G. 1995. New combinations in North American *Schoenoplectus, Bolboshoenus, Isolepis* and *Trichophorum* (Cyperaceae). Novon 5:97–102.

Smith, S.G. 2002b. *Schoenoplectus*. Vol. 2. Magnoliophyta: Commelinidae (in part): Cyperaceae. Flora of North America Editorial Committee, eds. Oxford University Press, New York. Pp. 44–60.

Smith, S.G. and G. Yatskievych. 1996. Notes on the genus *Scirpus* sensu lato in Missouri. Rhodora 98:168–179.

Smith, S.G. and E. Hayasaka. 2001. Delineation of *Schoenoplectus* sect. *Malacogeton* (Cyperaceae) new combination and distinction of species. J. Jap. Bot. 76:339–343.

Smith, S.G. and E. Hayasaka. 2002. New combinations within *Schoenoplectus smithii* and *S. purshianus* (sect. *Actaeogoton*, Cyperaceae) and comparison with eastern Asian relatives. Novon 12:106–111.

Sorrie, B.A. 1987. Notes on the rare flora of Massachusetts. Rhodora 89(858):139.

Steinauer, R.F. 2001a. 2000 Survey for *Schoenoplectus hallii* (Gray) S.G. Sm. in the eastern sandhills of Nebraska. Final report to the Nebraska Game and Parks Commission, Lincoln.

Steinauer, R.F. 2001b. 2001 Survey for *Platanthera praeclara* Sheviah & Bowles in Nebraska & *Gaura neomexicana* ssp. *coloradensis* (Rydb.) Raven & Gregory, Lodgepole Creek, Kimball & Cheyenne County, Nebraska. Final report to the Nebraska Game and Parks Commission, Lincoln.

Steyermark, J.A. 1963. Flora of Missouri. Iowa State University, Ames.

Strong, M. 1994. Taxonomy of *Scirpus, Trichophorum,* and *Schoenoplectus* (Cyperaceae) in Virginia. Bartonia 58:29–68.

Swink, F. and G. Wilhelm. 1994. Plants of the Chicago region. 4th Ed. Indiana Academy of Science, Indianapolis.

Takagawa, S., I. Washitani, R. Uesugi, and Y. Tsumura. 2006. Influence of inbreeding depression on a lake population of *Nymphoides peltata* after restoration from the soil seed bank. Conserv. Gen. 7:705–716.

The Nature Conservancy of Texas. 2007. An annotated list of rare plants of Texas. Austin.

Thomas, C.D., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F.N. Erasmus, M.F. de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A.S. van Jaarsvoid, G.F. Midgley, L. Miles, M.A. Ortega-Huerta, A.T. Peterson, O.L. Phillips, and S.E. Williams. 2004. Extinction risk from climate change. Lett. Nature 427:145–148.

Tucker, G.C. 1987. The genera of Cyperaceae in the southeastern United States. J. Arnold Arbor. 68:361–445.

U.S. Department of Agriculture. 2007. National Agricultural Statistics Service. Prospective plantings. Washington, D.C. http://www.nass.usda.gov/Newsroom/2007/03_30_2007.asp. Accessed Apr 2007.

U.S. Fish & Wildlife Service. 1993. Endangered and threatened wildlife and plants; review of plant taxa for listing as endangered or threatened species. Notice of review; 50 CFR Part 17. Federal Register Vol. 58. No. 188, Sep 30, 1993. Pp. 51143–51190.

U.S. Fish & Wildlife Service. 1996. Endangered and threatened wildlife and plants; notice of final decision on identification of candidates for listing as endangered or threatened. Notice of review; 50 CFR Part 17. Federal Register Vol. 61. No. 188, Dec 5, 1996. Pp. 64481–64485.

U.S. Fish & Wildlife Service. 2007. America's National Wildlife Refuge System- refuge planning- by Region. Washington, D.C. http://www.fws.gov/refuges/refugePlanning/. Accessed Jan 2007.

Venable, D.L. and L. Lawlor. 1980. Delayed germination and dispersal in desert annuals: escape in space and time. Oecologia 46:272–282.

Vitousek, P.M. 1994. Beyond global warming: ecology and global change. Ecology 75:1861–1876.

Voss, E.G. 1967. The status of some reports of vascular plants from Michigan. Michigan Bot. 6:13–24.

Watson, L.E. 1993. Monitoring of plant candidate species in Oklahoma–year two. Unpubl. Report to U.S. Fish & Wildlife Service. Oklahoma Biological Survey, Univ. of Oklahoma, Norman.

Weber, W.A. and R.C. Wittmann. 1992. Catalog of the Colorado flora: A biodiversity baseline. Univ. of Colorado Press, Niwot.

Wienhold, C.E. and A.G. van der Valk. 1989. The impact of duration of drainage on the seed banks of northern prairie wetlands. Canad. J. Bot. 67:1878–1884.

Wilcove, D.S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States. BioSci. 48:607–615.

Wilson, K.L. 1981. A synopsis of the genus *Scirpus* (Cyperaceae) in Australia. Telopea 2:153–172.

Winterringer, G.S. 1959. Notes on Cyperaceae from Illinois. Rhodora 61:290–292.

Wisconsin Department of Natural Resources. 2007. Working list: vascular plants. Madison. http://dnr.wi.gov/org/land/er/wlist/index.asp?mode=detail&Grp=20. Accessed Jan 2007.

Wisconsin Legislature. 2007a. Department of Natural Resources. Statute 29.604. Endangered and threatened species protected. Madison. http://nxt.legis.state.wi.us/nxt/gateway.dll?f=templates&fn=default.htm&vid=WI:Default&d=stats&jd=29.604. Accessed Apr 2007.

Wisconsin Legislature. 2007b. Department of Natural Resources. Statute NR 27 (03-07). Endangered and threatened species. Madison. http://www.legis.state.wi.us/rsb/code/nr/nr027.pdf. Accessed Apr 2007.

Yatskievych, G. 1999. Steyermark's flora of Missouri.Vol 1. Revised Ed. Missouri Department of Conservation, Jefferson City.

Yatskievych, G. and J. Turner. 1990. Catalogue of the flora of Missouri. Monogr. Syst. Bot. Missouri Bot. Gard. 37:1–345.